Water Power

INTERNATIONAL DEVELOPMENT OF HYDRO-ELECTRIC POWER

PRICE 2/6 APRIL 1953

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HYDRO-ELECTRIC

POWER IN INDIA

The Madras Government Irrigation and Power scheme depends on hydro-electric stations such as Mettur Dam shown. Metrovick generators, transformers, switchgear and protective apparatus, etc., are used extensively on the system. Mettur station contains 4 Metrovick 12,500 kVA generators.

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MANCHESTER 17, ENGLAND

Member of the A.E.I. group of companies

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prior to shipment of
66-kV small-oil-volume circuit-
breakers

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Equipment for Hydro-Electric Power Stations

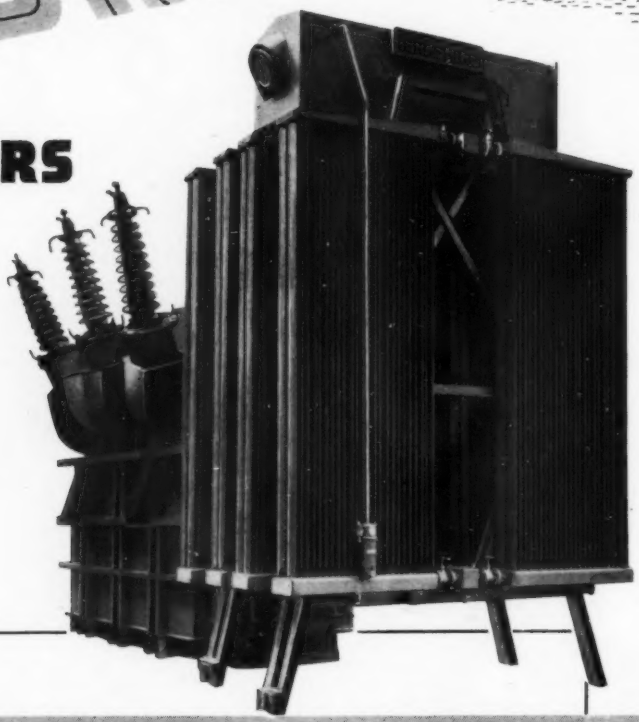
Penstock Butterfly Valves, automatically closing in case of pipe rupture

Complete barrage installations; gates and hoisting equipment, gantry- and overhead travelling cranes, trash screen cleaning machinery; sluice gates; control valves for high pressure conduits; automatic safety organs for pipe lines; discharge regulating valves, rotary valves with rotary-piston servomotors, needle valves, butterfly valves, high pressure fittings, piping systems for oil and cooling water plant; funicular and aerial cableways for passenger and goods transport; building machinery for dam-building work.

Louis de Roll, Ironworks Ltd., Works at Gerlafingen, Klus, Choindez, Rondez, Olten, Berne (Switzerland)

YORKSHIRE

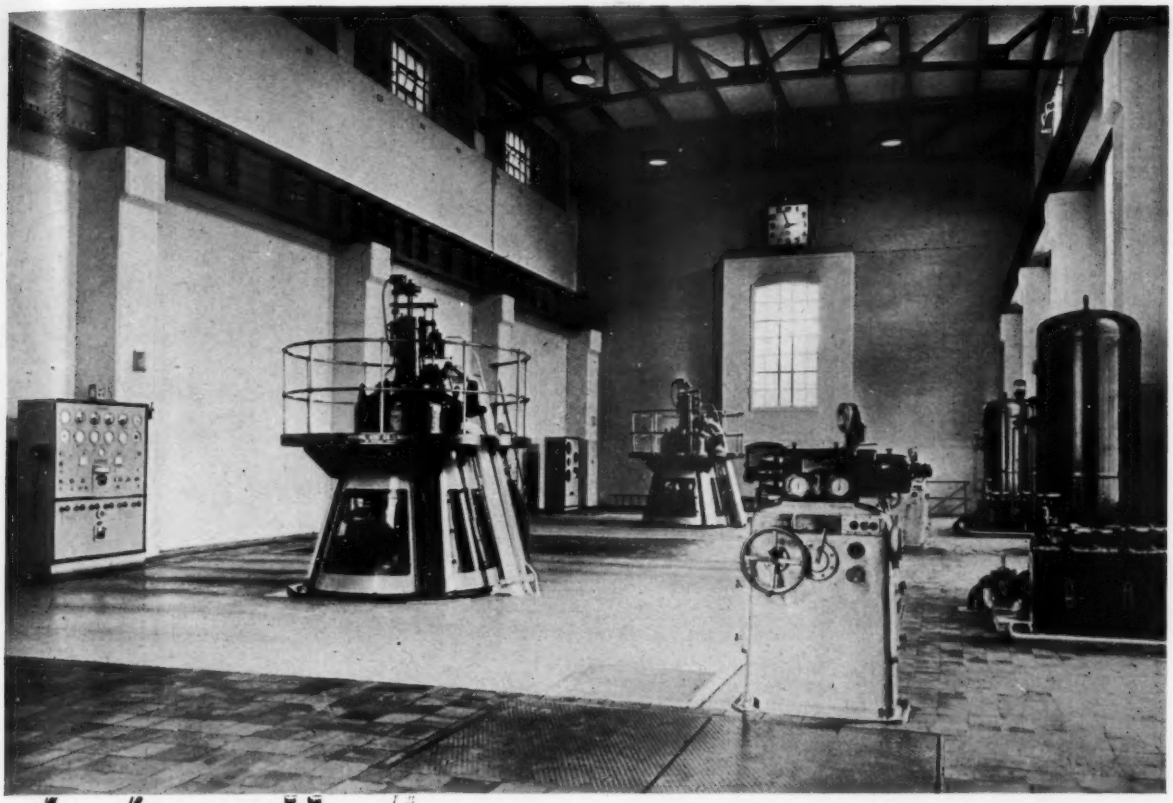
POWER TRANSFORMERS



We specialise in manufacturing Power Transformers for Generation, Transmission and Distribution.
All YORKSHIRE Transformers are designed, constructed and tested to the corresponding British Standard Specification.
We make Transformers to suit all requirements up to 60,000 kVA.—132,000 volts.

Yorkshire Electric Transformer Co. Ltd.

THORNHILL DEWSBURY YORKSHIRE *Phone: Dewsbury 1691-2*



'Kaplans for low heads'

a typical development

Boving Kaplan turbines have been installed in many major hydro-electric plants throughout the world and are operating at high efficiency under widely diverse conditions of head and output. The first plant was installed in 1929 in New Zealand. The best technical knowledge and experience together with thorough workmanship is incorporated in every Boving installation.

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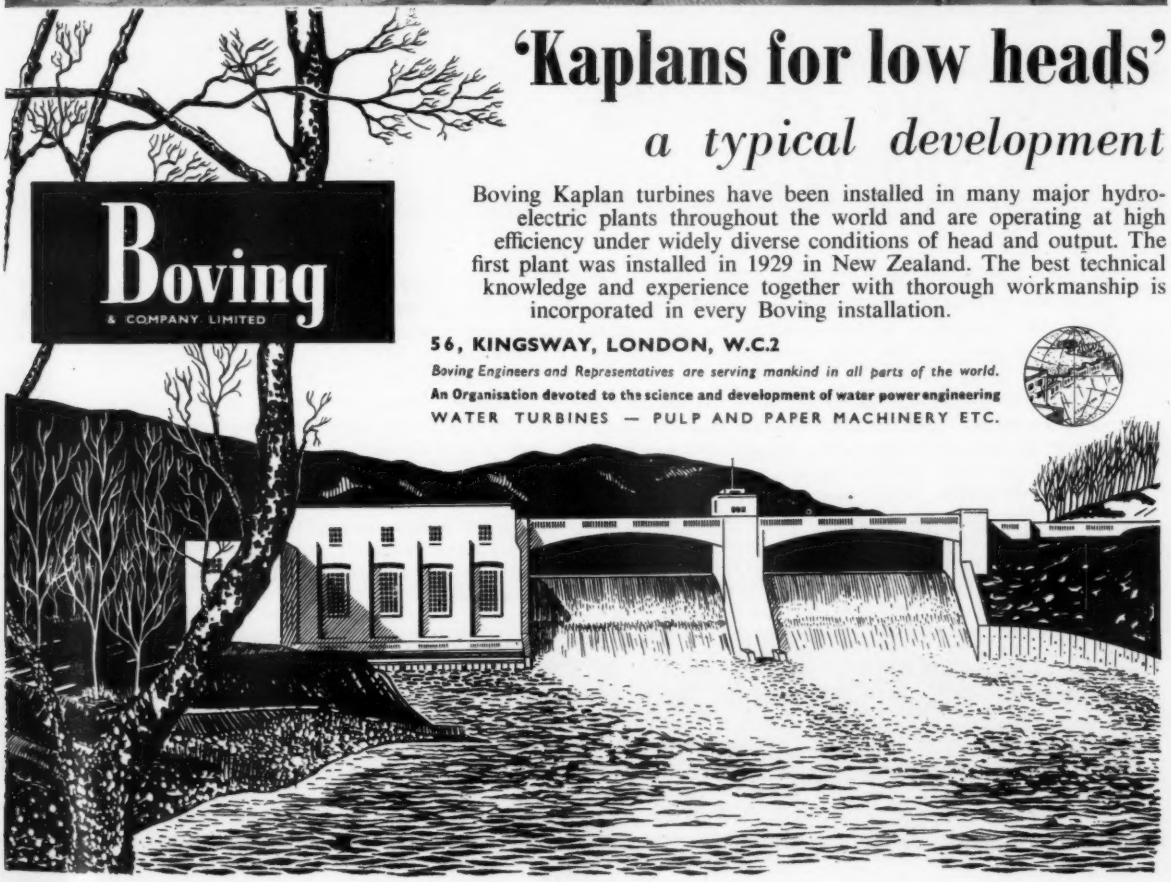
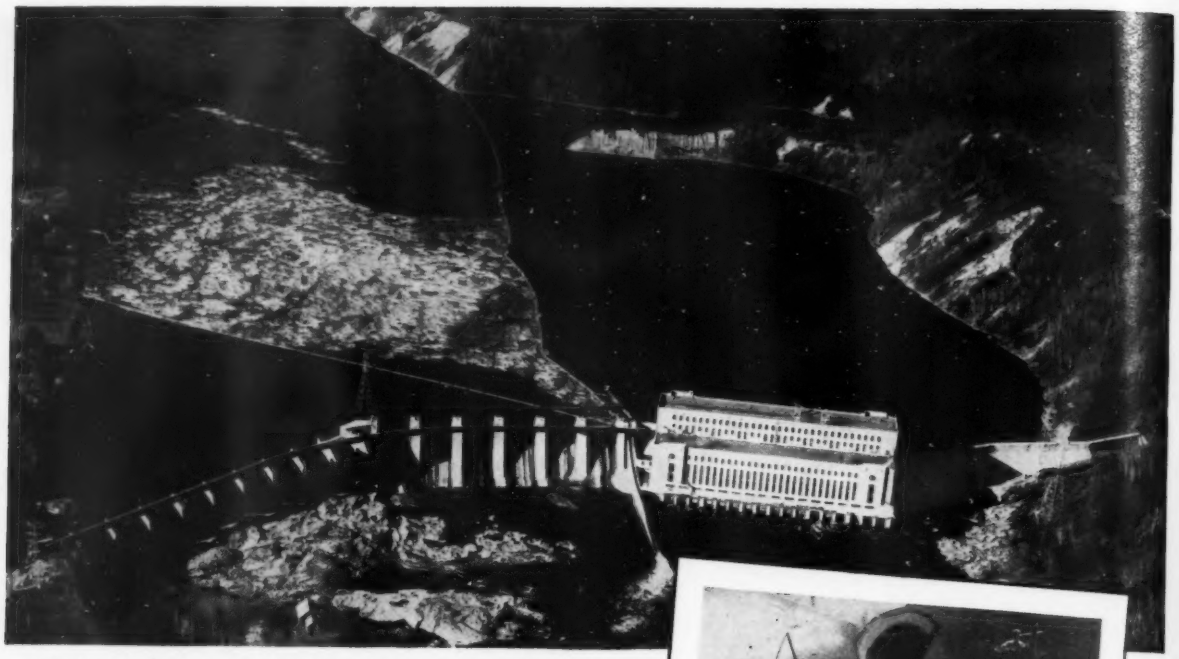
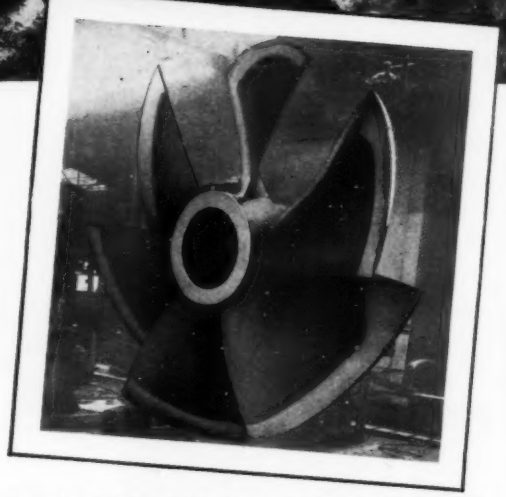
An Organisation devoted to the science and development of water power engineering

WATER TURBINES — PULP AND PAPER MACHINERY ETC.





The La Gabelle plant of the Shawinigan Water and Power Company, containing five Dominion fixed blade propeller turbines of 35,000 H.P. each, at 120 R.P.M. under a head of 60 feet.



Economy with DOMINION PROPELLER TURBINES

For low head hydro-electric power plants, where high speed is essential for economy in capital cost, the fixed blade propeller turbine is often the most suitable particularly when there are multiple units in the power house.

The fixed blade propeller turbine is as simple in construction and operation as the lower speed Francis turbine. It does not require the complicated mechanism and governor control, in the rotating element, of the adjustable blade propeller turbine. Nevertheless, the fixed blade propeller turbine, in many installations, utilizes the available hydraulic power as effectively as the more expensive type.

Since 1921 Dominion Engineering have received orders for 89 fixed blade propeller turbines with a total rated capacity of 1,244,245 H.P., and are now manufacturing 14 units of this type, with throat diameter of 205". Eight units, of 21,000 H.P. each, at 94.7 R.P.M. under a head of 40 ft. are for the Chenaux Development of Hydro-Electric Power Commission of Ontario, and six units of 19,000 H.P. each, at 94.7 R.P.M. under a head of 37 ft. are for the Pine Falls Development of Department of Mines & Natural Resources, Province of Manitoba.

This background of experience, combined with a systematic research programme in our own laboratory, is at your service. We confidently invite your enquiries.

4907

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COMPANY LIMITED
MONTREAL, CANADA **D** **CABLE: DOMWORKS**

New Power From Chile's Glacial Watersheds!

Chile is building a series of hydro-electric stations to provide sources of inexpensive power for industry and transportation, utilizing glacial watersheds in the Andes. The first two stations to be built and put in operation were Abanico and Pilmaiquen. Chilean engineers surveyed their country's potentialities . . . picked sites for development at the lowest cost and greatest efficiency. Then G-E engineers teamed with Chilean engineers, gathered data on the spot, designed, built and tested the electrical equipment.

These hydro-electric stations are one example of G-E installations located throughout the world.

EQUIPMENT INSTALLED General Electric equipment installed at Abanico and Pilmaiquen consists of generators, switchgear, control, transformers. Abanico's four 21,500-kva water wheel-driven generators now produce 86,000-kva at 13,200 volts, 50 cycles. This is stepped up to 154,000 volts for transmission. Part of this power supplies the new Huachipato steel mill, also G-E equipped.

COMPLETE ENGINEERING SERVICE G-E facilities and representatives stand ready to help you with every electrical need and problem. Get the facts from your nearest G-E representative. Or write International General Electric Co., Apparatus Sales, 570 Lexington Ave., New York 22, N.Y., U.S.A. 1A-53-30E

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Leffel

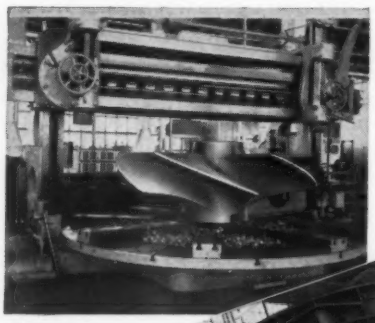
HYDRAULIC TURBINE

increases

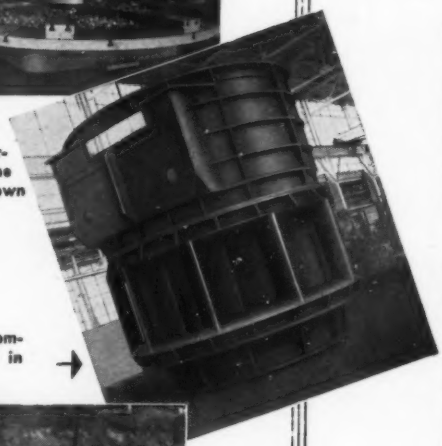
power output at

WILBUR DAM

of the Tennessee Valley Authority



Cast steel propeller-type runner for the Wilbur turbine, shown on boring mill.

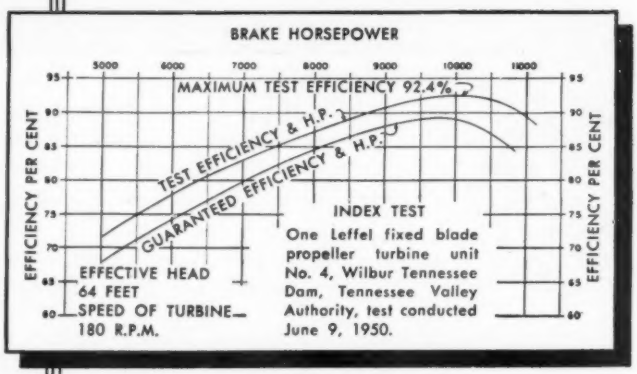


Wilbur turbine, completely assembled in the Leffel plant.

Lifting the combined runner, shaft and coverplate during the field installation.

The Wilbur power project of the TVA is another instance where a Leffel hydraulic turbine was used for the expansion of existing power facilities. For the Wilbur installation a Leffel vertical propeller-type hydraulic turbine was used — maximum rated at 11,500 HP, under 67 feet net head, speed 180 RPM.

The Wilbur project demonstrates once again that the long-range economy and dependability of Leffel turbines make a valuable asset for any expansion or rehabilitation. Our facilities are backed by 91 years of reliable service to the water power industry. Why not let us help you with your project, whether it be expansion, rehabilitation or a new installation?



Field Test Results

1082

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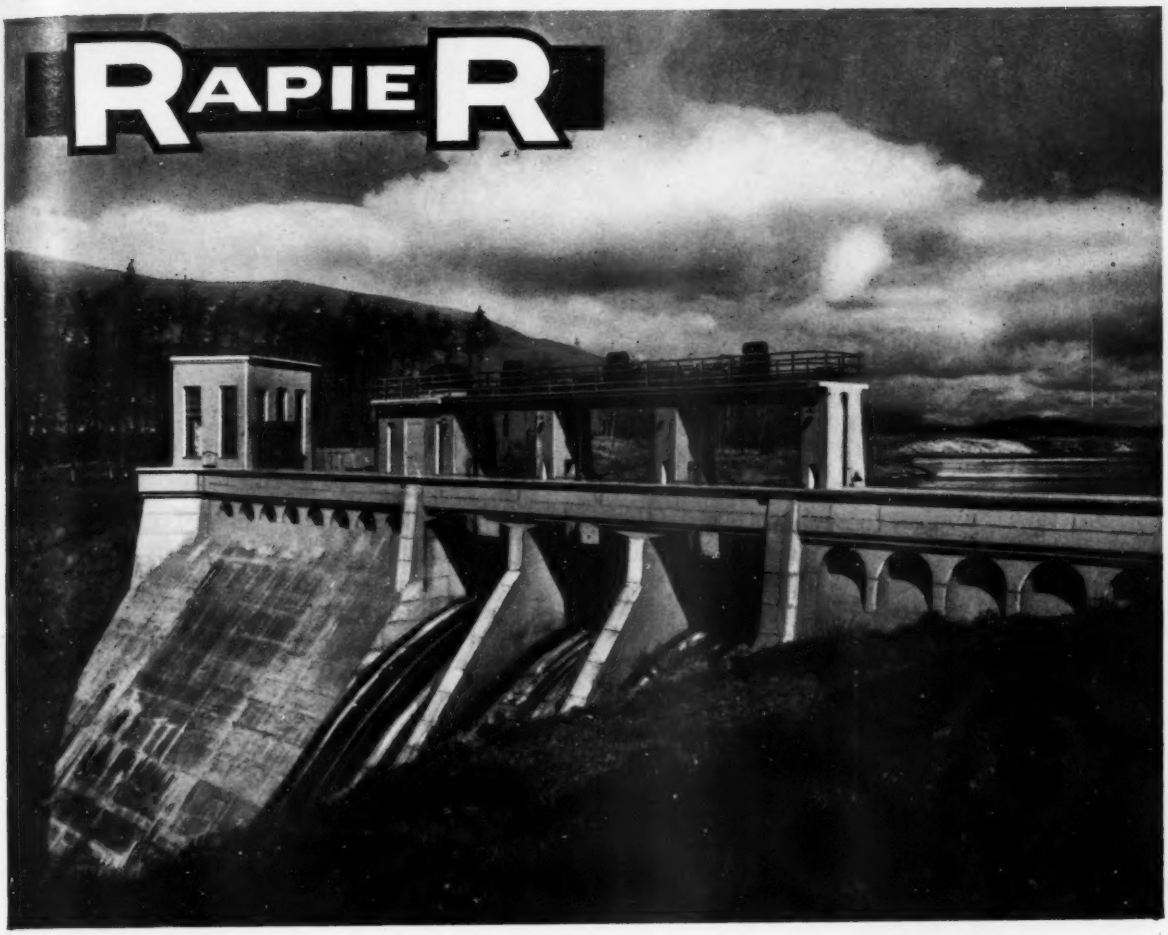

RAPIER

A typical installation of RapieR Gates for Spillway and Tailrace at the dam for Pollaphuca Power Station on the River Liffey, Eire.

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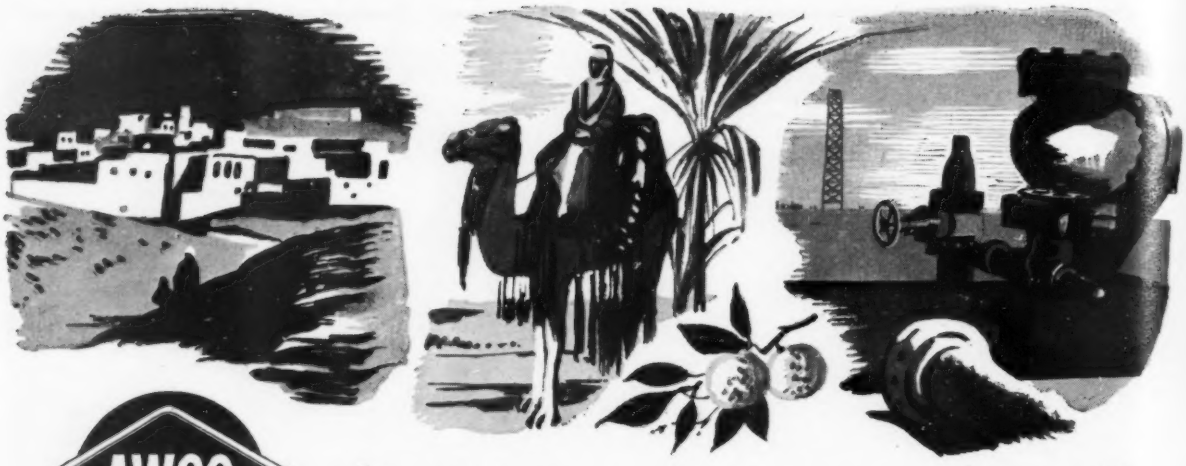

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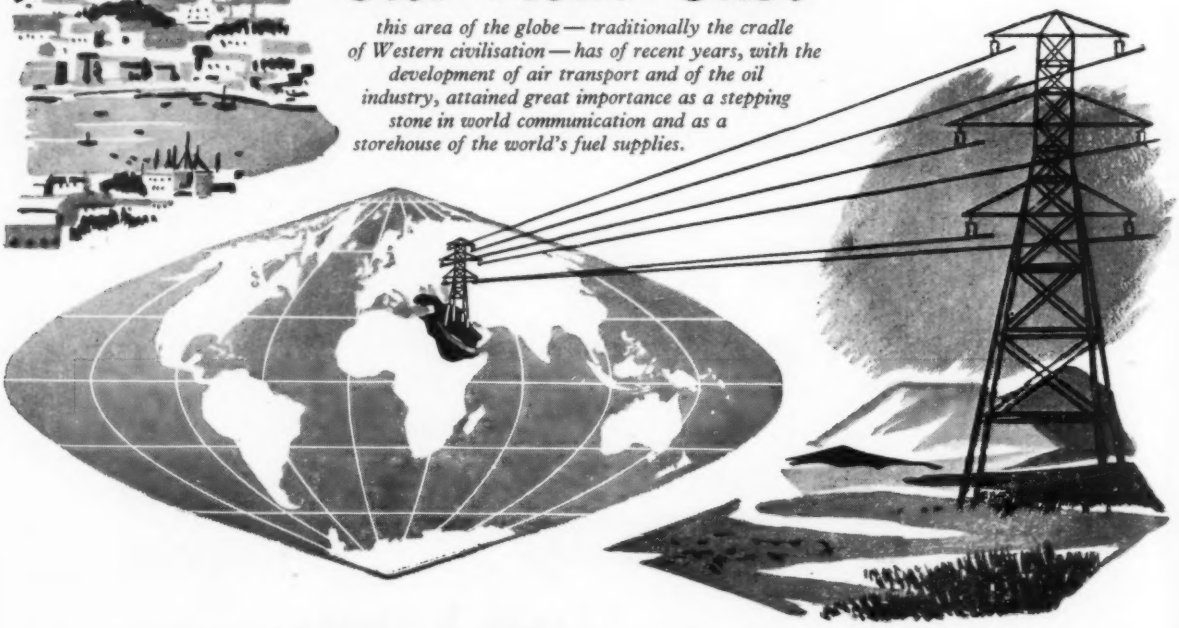
Aluminium conductor spans the world

Tapping the world's natural resources would be a completely fruitless endeavour were there no means to carry power to the point at which it can most profitably be employed. Aluminium conductors of all types enable this to be done in the most economical manner over any distance with a minimum energy loss.

The Near East

this area of the globe — traditionally the cradle of Western civilisation — has of recent years, with the development of air transport and of the oil industry, attained great importance as a stepping stone in world communication and as a storehouse of the world's fuel supplies.



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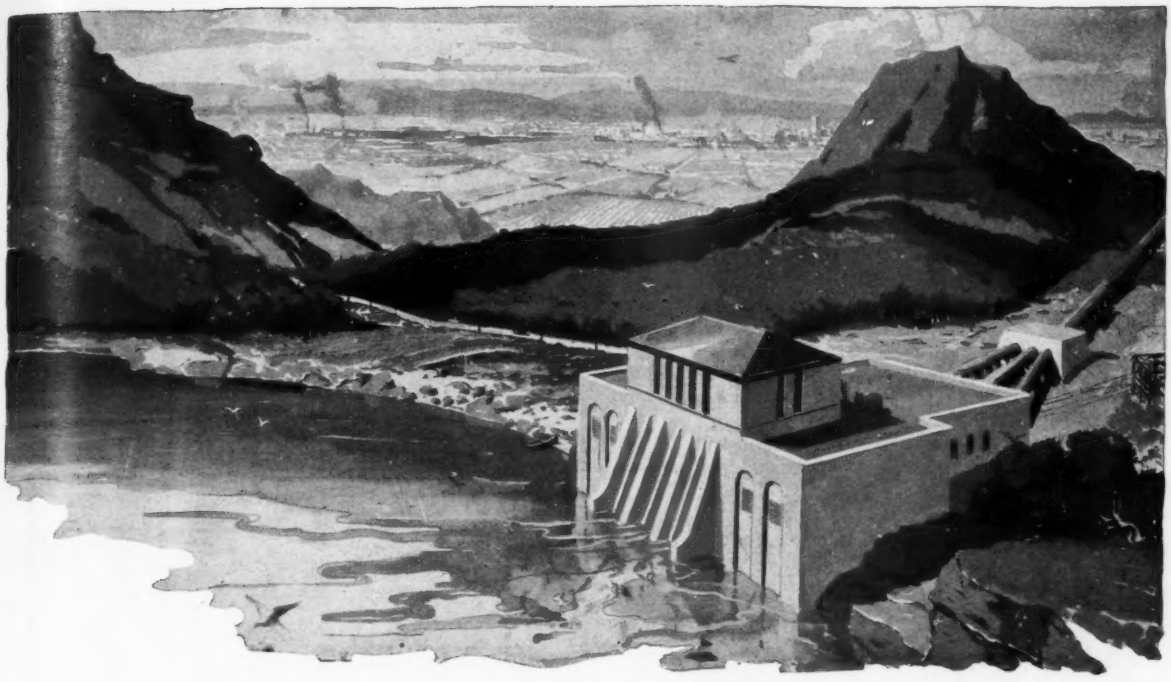
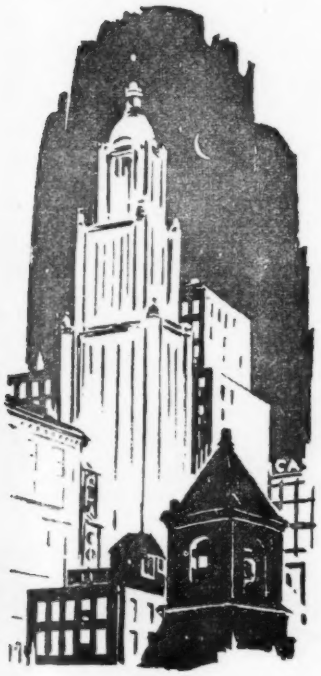


WHEN Millions Live As One



ADVENTURESOME folk, since the beginning of time, have migrated . . . Settling in tiny clusters . . . Spreading spider-web fashion to dot the land with villages and towns . . . While others pressed forward, facing dangers concealed behind each rock and tree!

But with the growth of cities, new perils arose and multiplied . . . People were living too closely together . . . Epidemics and pestilence exacted their toll.

Then science and modern machinery rescued them from exposure to disease emanating from impure water and unsanitary waste disposal . . . And today, *millions live as one!*

Rotovalves and Axial Flow Pumps, by Smith, are in service—controlling water, controlling floods and regulating sewage discharge in important systems, far and wide.

The recognition and acceptance given these products are not accidental. They come from superior design, resulting from our more than 77 years of hydraulic experience . . . Facts that are significant, because they are proof positive of our ability to serve you, *if you place your problem in our hands!*

The Harland Engineering Co. Ltd., Alloa, Scotland, Manufacturing Licensees for the British Commonwealth.

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ALTERNATORS
for Hydro-Electric Power Stations

Mounting in our Works of a new 30,000 kVA - 6,600 Volts - 333 R.P.M. vertical-shaft alternator. This machine will equip the DELCOMMUNE Power Station, N'zilo Falls, and will contribute, with two other identical Units now under construction, to the industrial development of the Belgian Congo.

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CHARLEROI CAEC

KMW

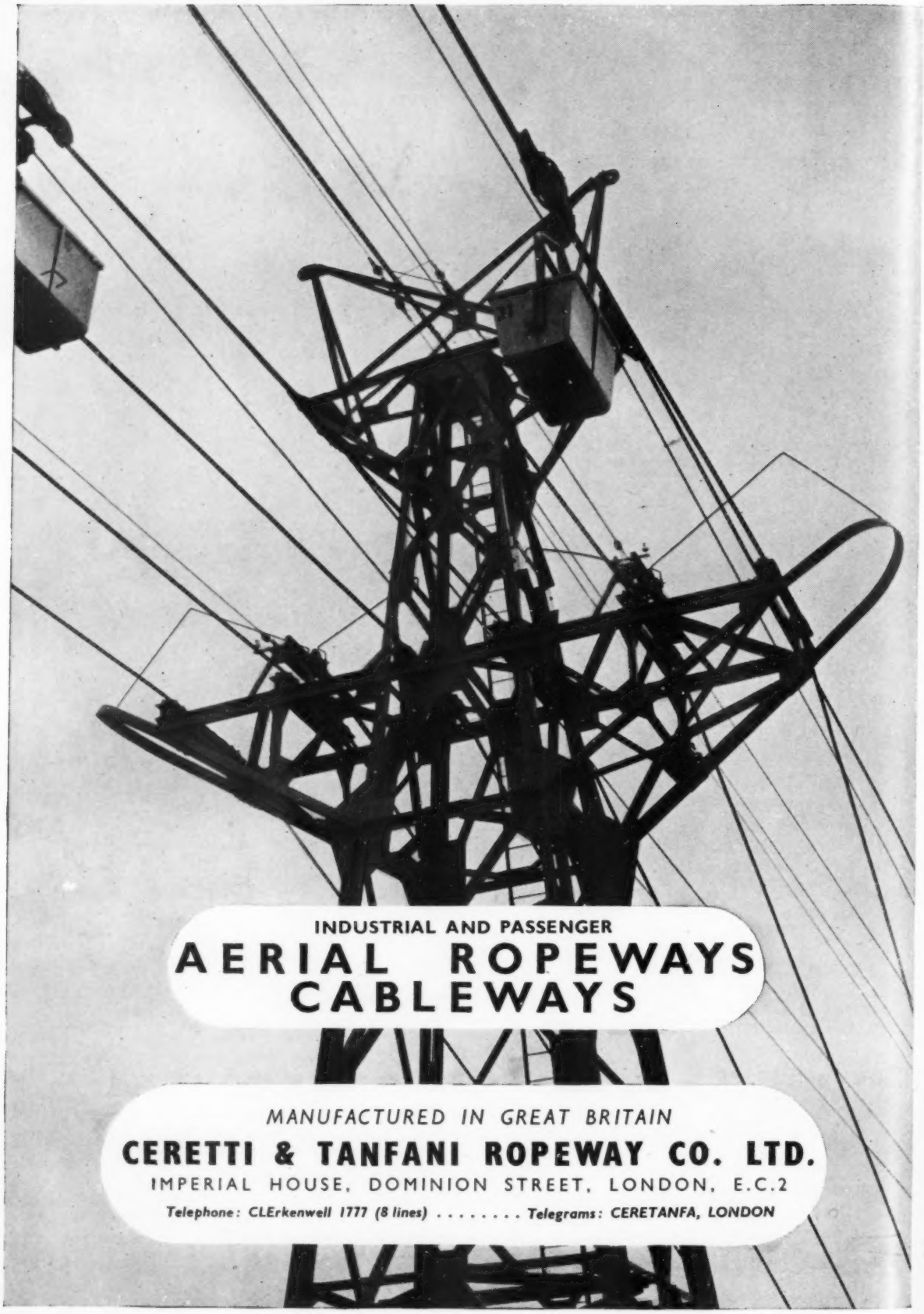
Runner for *one of the three* KMW Turbine Units of the Kilforsen Power Plant, owned by the Royal Swedish Board of Waterfalls.

Output : 121,350 H.P.
Head : 327 feet.
Speed : 166.7 r.p.m.
Water Quantity : 3615 cusecs.

The stainless steel runners are solid cast by Domnarfvet Steel Works, Sweden, and finished at KMW's works at Kristinehamn. They have a net weight of 35 tons each.

AKTIEBOLAGET KARLSTADS MEKANISKA WERKSTAD

KARLSTAD • SWEDEN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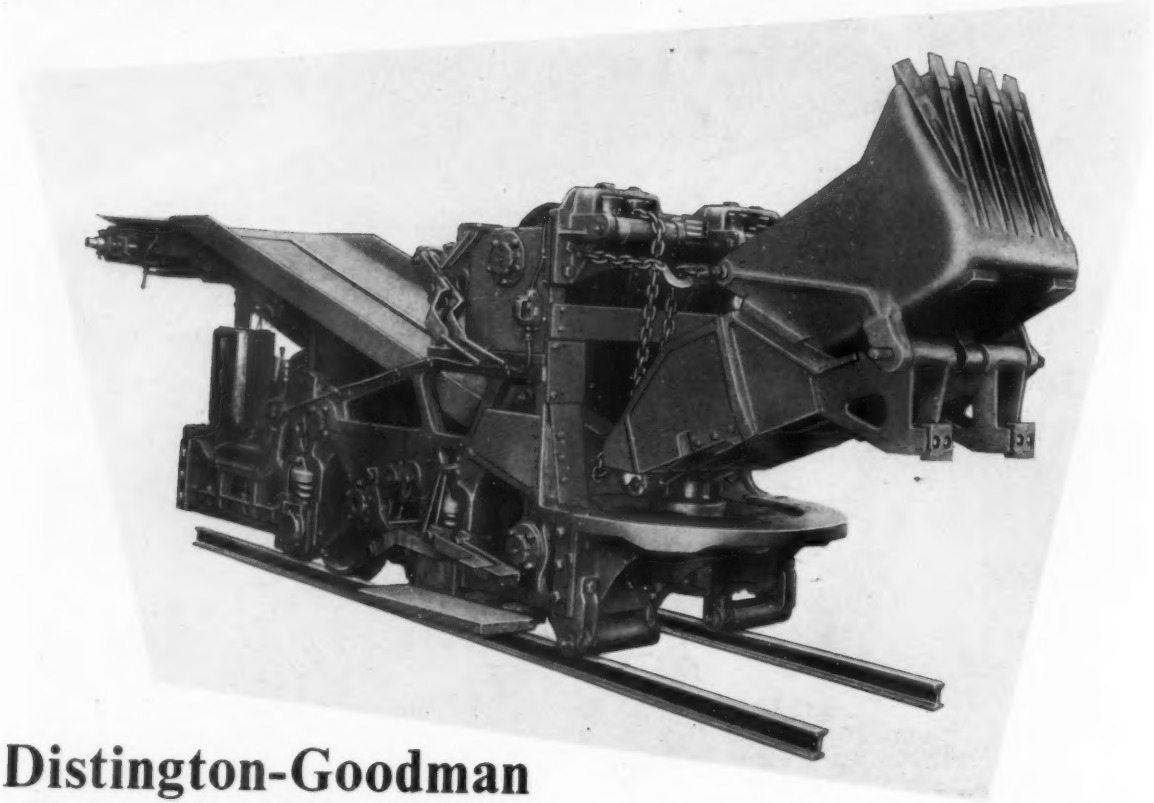
FOR RAPID DRIVING . . . .



Distington-Goodman Type 75 Tunneller

The clean-up width of the Type 75 Tunneller ranges from 13 feet to 20 feet 9 inches according to the length of boom fitted.

This type of machine can be built for track gauges as narrow as 24 inches or as wide as 42 inches although the gauge may determine the maximum length of boom that can be fitted. Dual gauge machines have been designed to use a narrow gauge track for locomotion, and a wider track to give greater stability to the machine during loading operations.

The machine has four loading motions which can be combined or used independently, and which are controlled by two quick-action hand levers and two foot levers. Each control lever actuates a friction band on a planetary gear drum, giving smooth take-up of power and protection against overload in addition to that afforded by the electrical control gear.

A single electric motor provides the power for all loading and tramming movements and for driving the discharge conveyor. If required, a separate motor can be fitted to drive the conveyor.

MOTOR HORSE-POWER		75
WEIGHT (TONS)		16
DIPPER CAPACITY (three sizes)		13½ cu. ft. ⅝ cu. yd. ¾ cu. yd.
LOADING CAPACITY cu. ft. per minute depending on size of dipper		82 101 121
LOADING CYCLES PER MIN.		6
TRAMMING SPEED ft. per min.	FORWARD	180
	REVERSE	123

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G.T. 2

a giant spark between horns . . . .

A giant spark leaps between the horns - the eye records a line of blue fire - the ear rings with its detonation and in the micro-seconds of its travel the camera arrests its motion, pictures its pattern and presents a perfect record for laboratory study.

In this photograph, streamers to the cap of the third unit are clearly shown — information that will help the engineers to progressive improvement - constant research that ensures the consistent quality of T.T. Insulators, thoroughness in design setting a self-imposed standard so high that only the finest skill and craftsmanship can maintain it. The skill and craftsmanship of the Taylor Tunnicliff organisation that has made them Masters of Porcelain Insulation.

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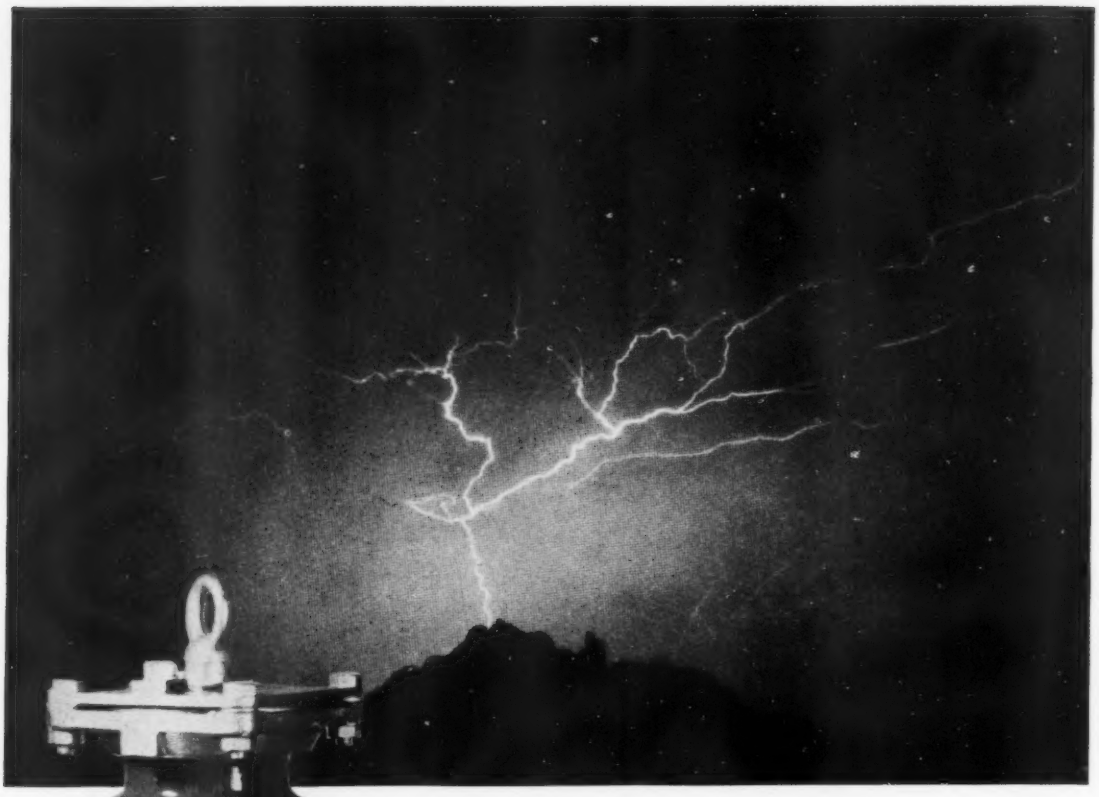

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to avoid tripping of circuit-breakers and damage to equipment due to over-voltages during thunderstorms ?

to utilize your equipment to the full even during periods of frequent lightning storms ?

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The CEMENTATION COMPANY LIMITED

Progress of over 1,000 feet of completed 8′ 6″ dia. circular lining of the eleven mile long Bowland Tunnel is being obtained on one face in a six day week. This requires the production on the site of over 3,000 tons of aggregate and a four mile underground haulage of 2,500 cu. yds. of concrete from the central mixing plant at Croasdale Shaft. The illustration shows the steel shuttering for the full section of the tunnel. The concrete placing pipe can be seen in the roof. The process of placing the lining is continuous.

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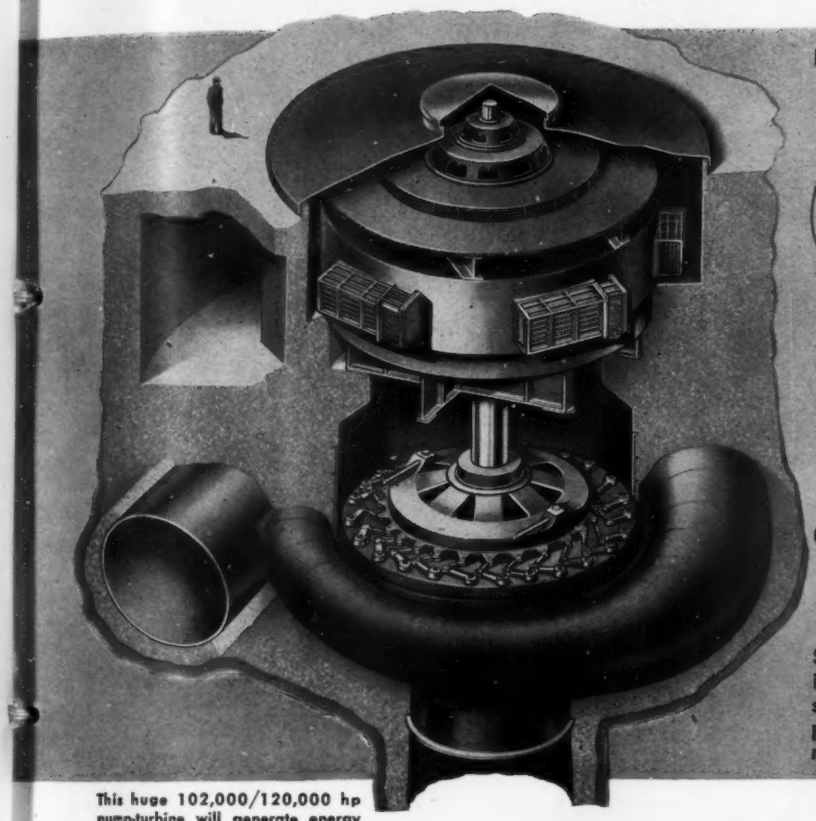
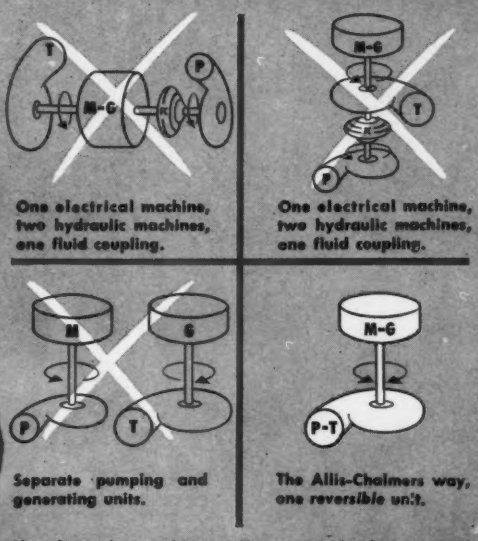
ALLIS-CHALMERS Pioneers *REVERSIBLE* Pump-Turbines!



This huge 102,000/120,000 hp pump-turbine will generate energy during peak demand periods, then reverse and — using surplus power from other plants — restore water to the reservoir during off-peak periods. Power value differential will make operation economical.

HOW REVERSIBLE PUMP-TURBINE REDUCES EQUIPMENT NEED



Sketches above show different methods of applying motive and generating equipment for pumped storage. Note that the Allis-Chalmers reversible pump-turbine at lower right requires least equipment and simplest power plant construction.

NOW BUILDING 5 UNITS FOR PUMPED STORAGE

THIS RECORD SIZE pump-turbine is now under construction by Allis-Chalmers for the Hiwassee dam in North Carolina. It combines in one reversible, two-element unit an electrical machine rated 102,000 hp as the world's largest motor and a hydraulic machine with the world's largest Francis runner.

When operating at maximum head as a turbine, this reversible unit will develop 120,000 hp. As a pump, it will move a maximum of 5200 cfs, 3.3 billion gallons per day . . . three times the capacity of the largest existing pump.

Allis-Chalmers — builder of over 12 millions of installed hydraulic horsepower — pioneered the development of the reversible pump-turbine for pumped storage. A-C offers you undivided responsibility, being able to design and build *all* elements of an entire reversible pump-turbine unit.

Of the five reversible pump-turbines A-C is now building, the Hiwassee unit is the largest. First scheduled for service is the 12,650 hp unit for the Flatiron Power & Pumping plant in Colorado. Three 19,000 hp units for the Sao Paulo Light & Power Co., Ltd., Brazil are now being built at Canadian Allis-Chalmers, Ltd., Montreal.

You get the real design advances *first* from Allis-Chalmers. And dealing with A-C is convenient, too, with 95 sales offices and 65 distributors located in 53 countries. For your free copies of Reversible Pump-Turbine Bulletin 01R7784 and illustrated, 56-page Bulletin 02B7301 of world famous hydro plants, just call your nearest A-C distributor or write to Allis-Chalmers, Milwaukee 1, Wisconsin, U.S.A. A-4011

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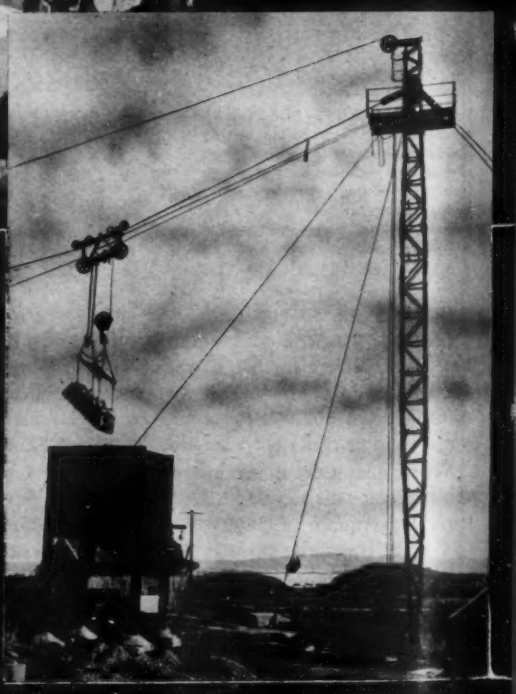
A-C ALLIS-CHALMERS

ESSENTIAL FOR DAM CONSTRUCTION



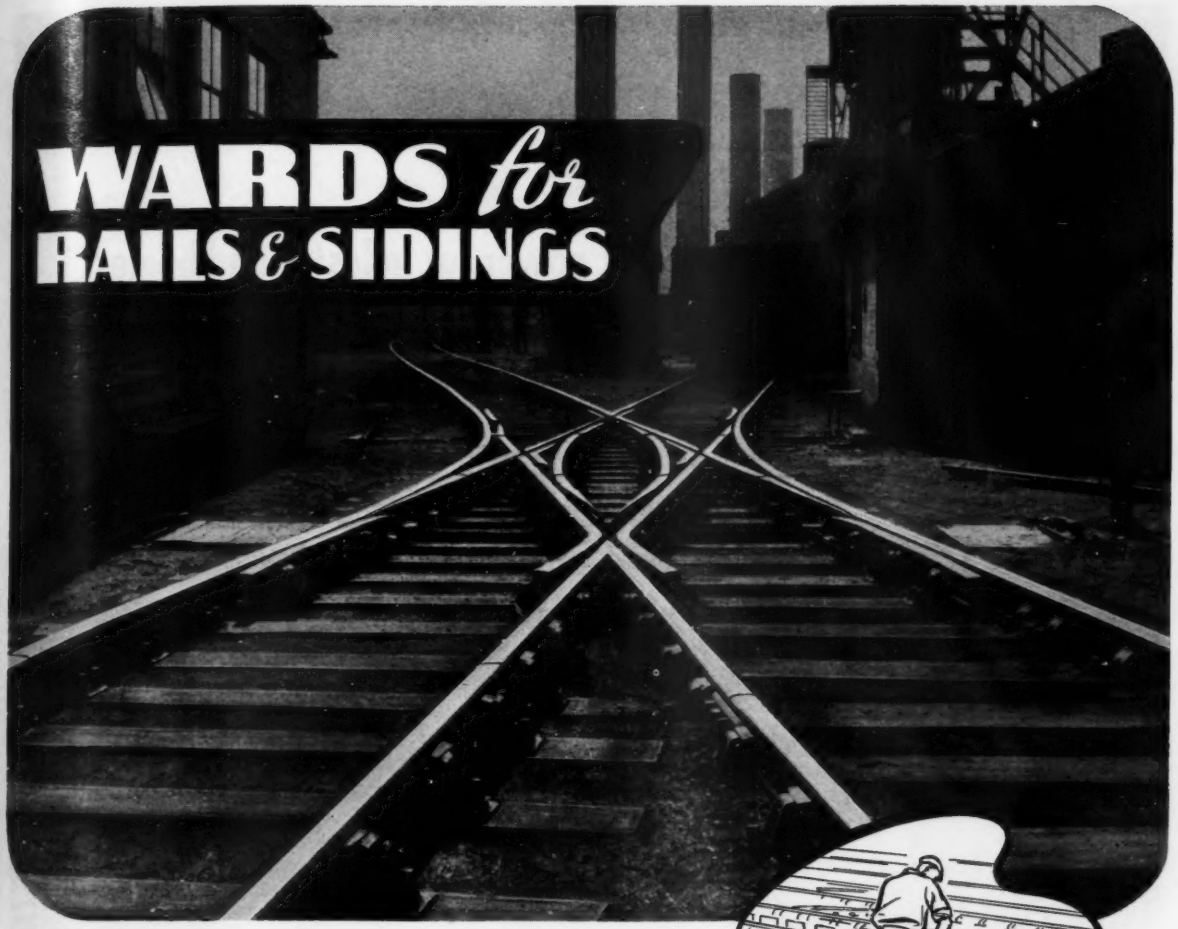
Giant hydro-electric schemes in all parts of the world make use of BRECO Aerial Ropeways and Cableways.

One of the largest builders of heavy capacity Ropeways and Cableways in the world, BRECO will supply advice and technical information willingly, and without obligation.

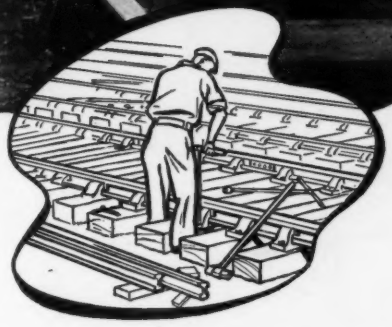
BRECO *Aerial* ROPEWAYS

BRITISH ROPEWAY ENGINEERING CO LTD PLANTATION HOUSE MINCING LANE LONDON E.C.3

WARDS for RAILS & SIDINGS



The siding pictured above shows a double slip layout—part of a contract recently completed for the Yorkshire Generation Division, British Electricity Authority.



IN the planning and construction of railway sidings, Wards offer a high degree of technical skill and experience. Wards have been building sidings for nearly half-a-century and thus bring to the subject an extensive knowledge of a variety of operating conditions.

Similarly, in the supply of railway equipment generally Ward's Rail Department service covers new and re-usable rails of all normal sections, as well as switches, crossings, turnouts, buffer stops, etc. Associated supplies include colliery arches, pit props, roofing bars, floor plates and, of course, all manner of track accessories and tools.

In short, Wards offer a comprehensive service on every aspect of railway siding planning, construction and maintenance for industrial operation.

The Railway Siding Consultants and Contractors

THOS. W. WARD LTD

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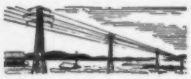

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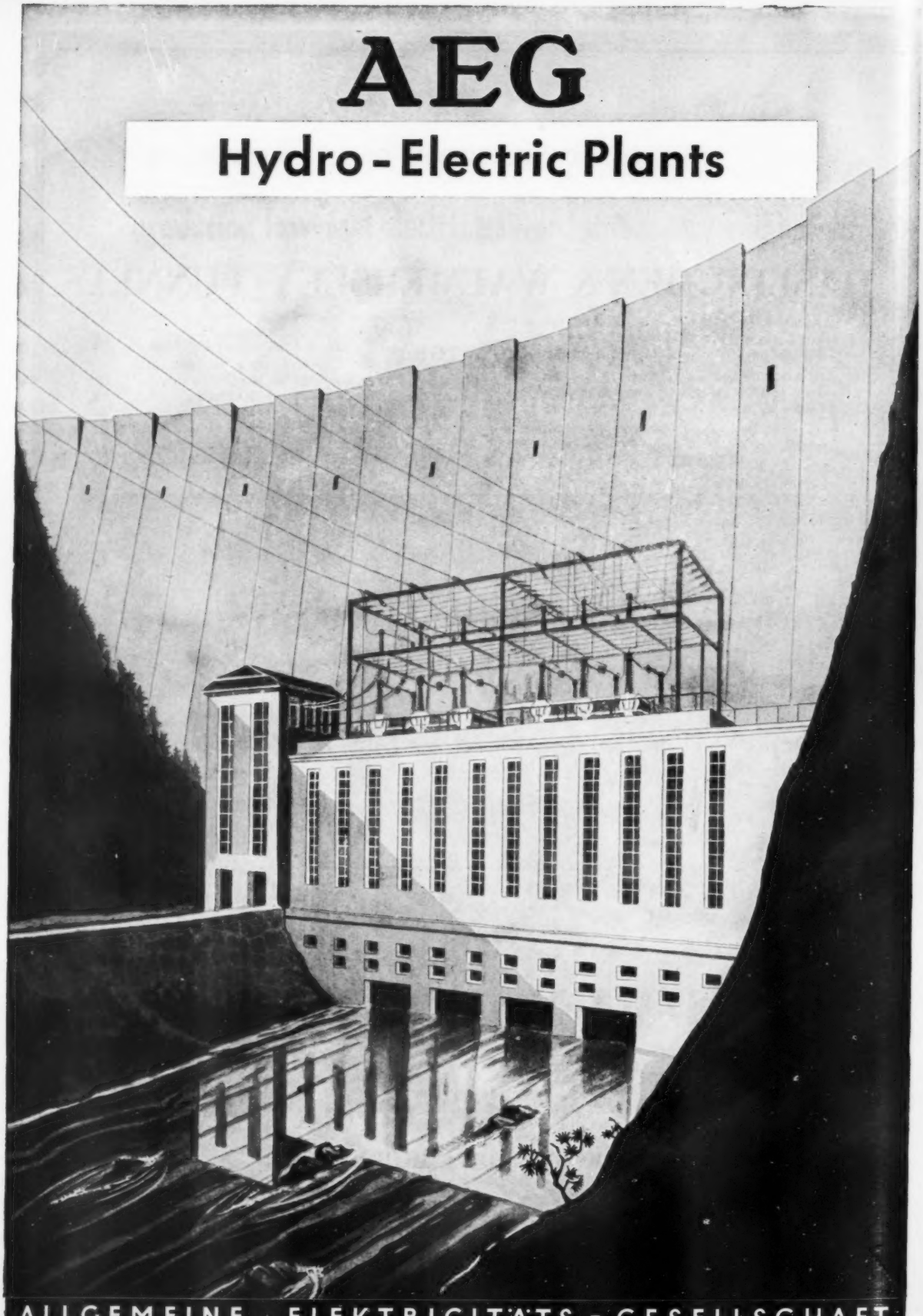

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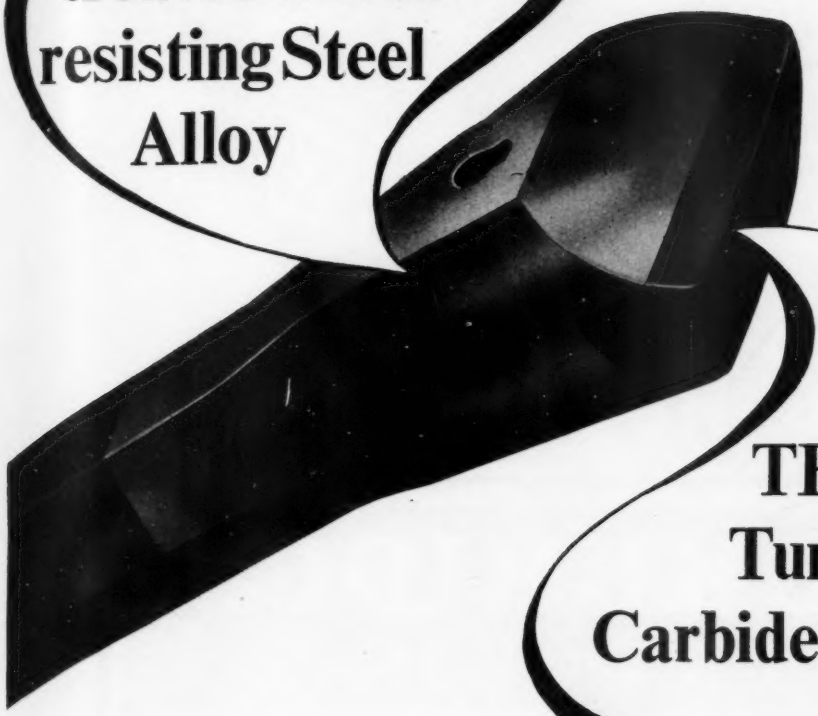

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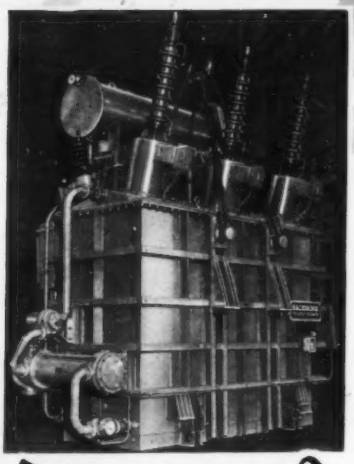

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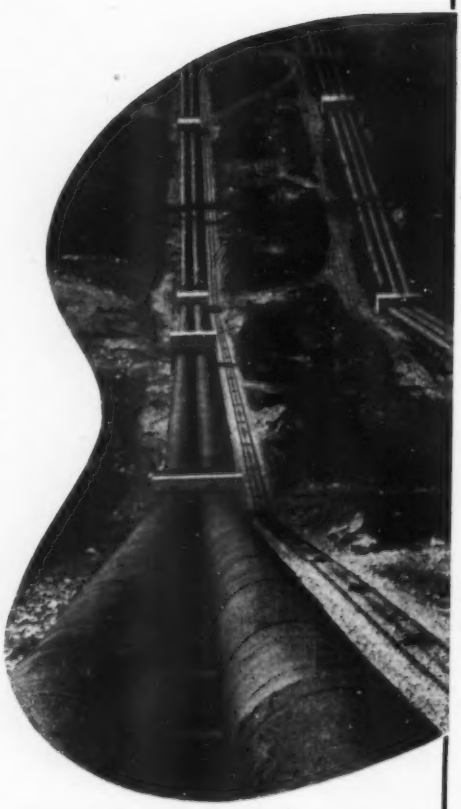

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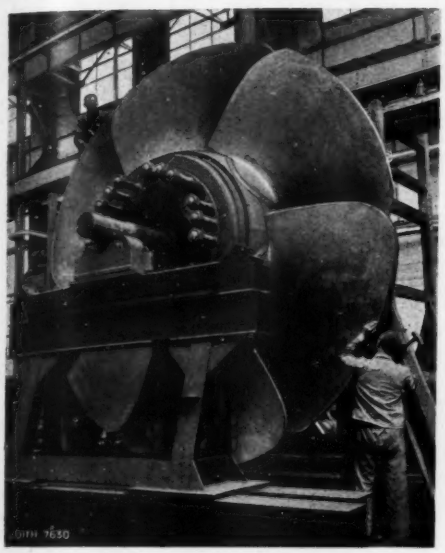


Illustrations:

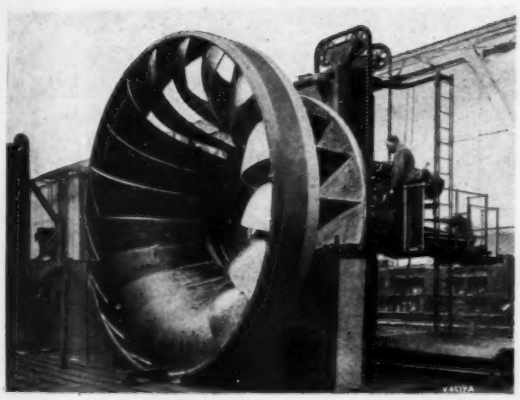
On the left: 34,600 H.P., Hirakud II (India)

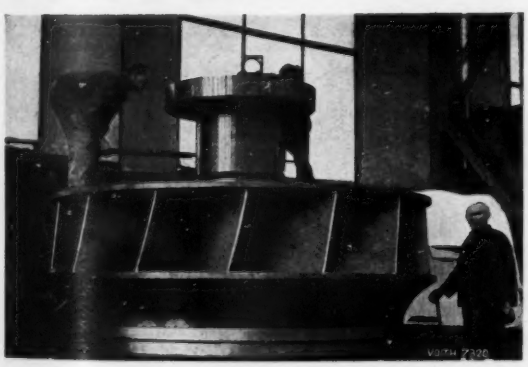
Below: Runner 15 feet diameter, 115,500 H.P., Sungari (Manchuria)

On the right: 52,400 H.P., Cipreses (Chile)

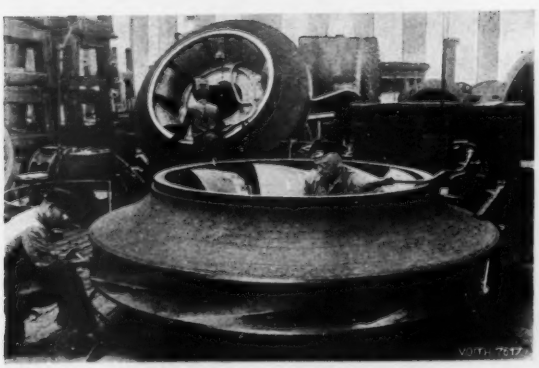
Below: Split runner 16' 5" diameter, 60,000 H.P., Parahyba (Brazil)

In the foreground: the runner model





Runner 60,000 H.P. output, Waldshut (Germany)



Storage Pump Impeller 24,100 H.P. input, Waldshut

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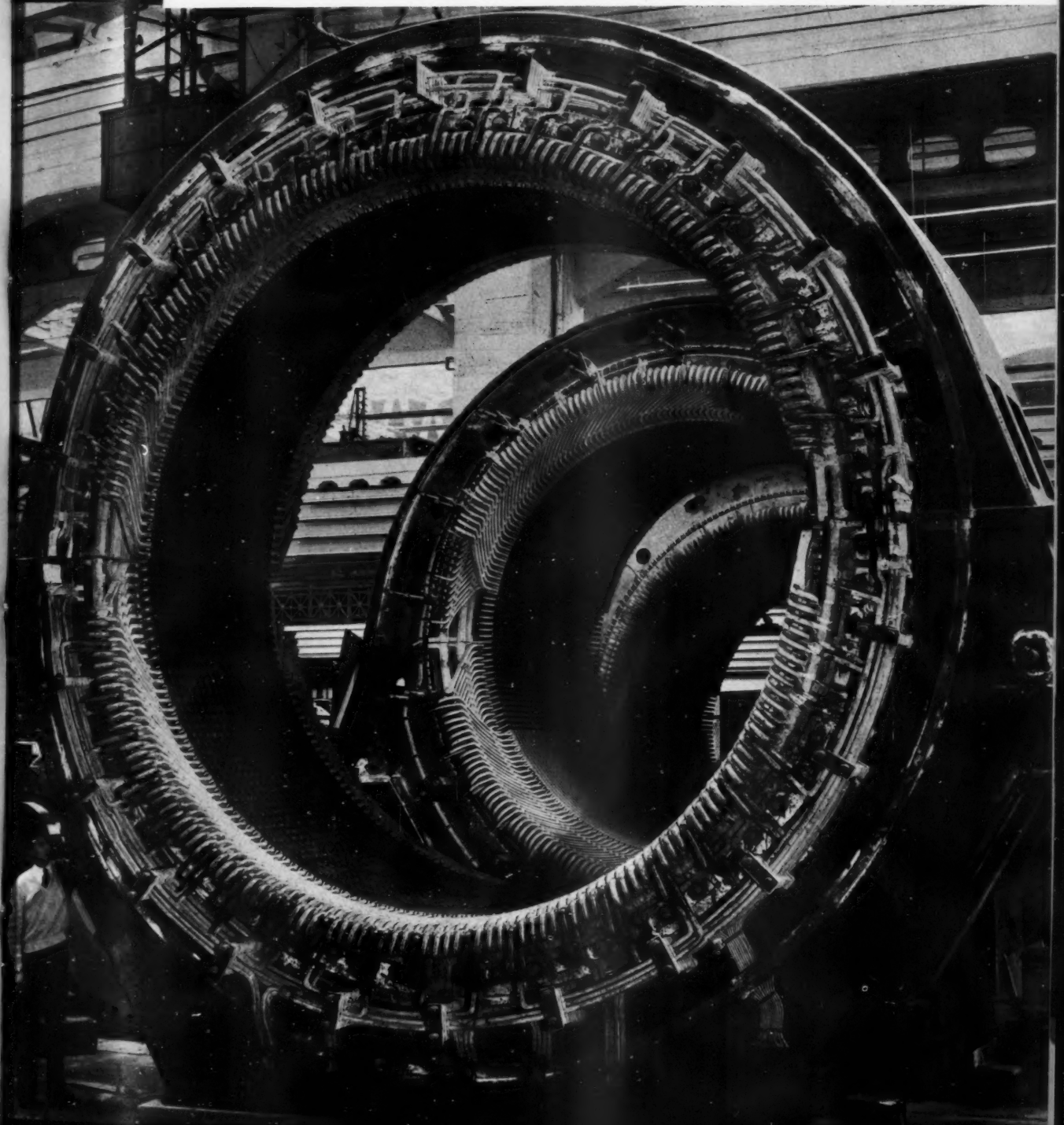

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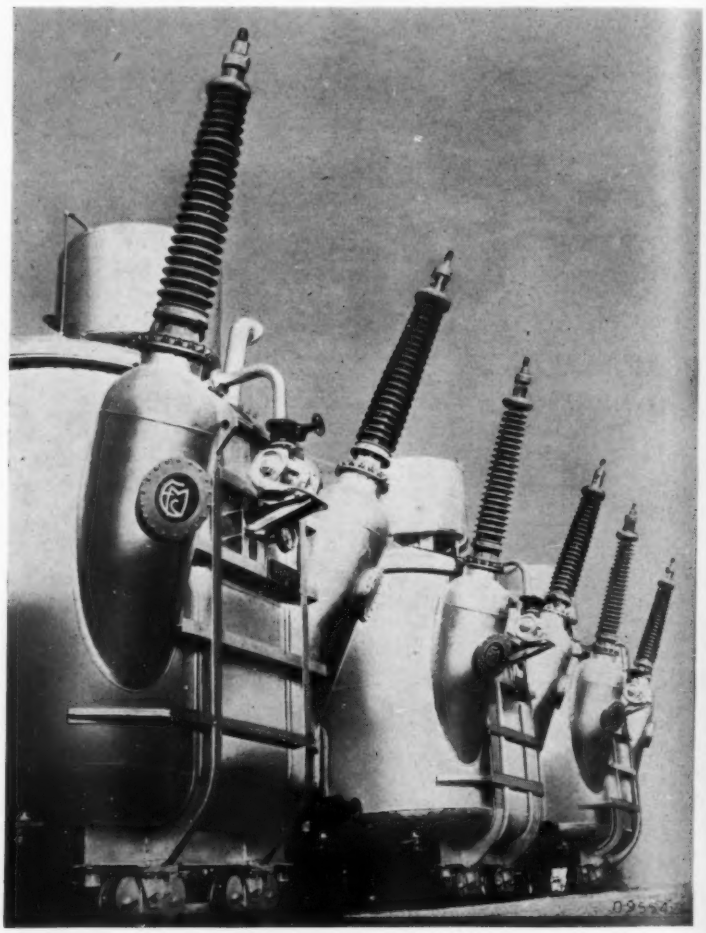

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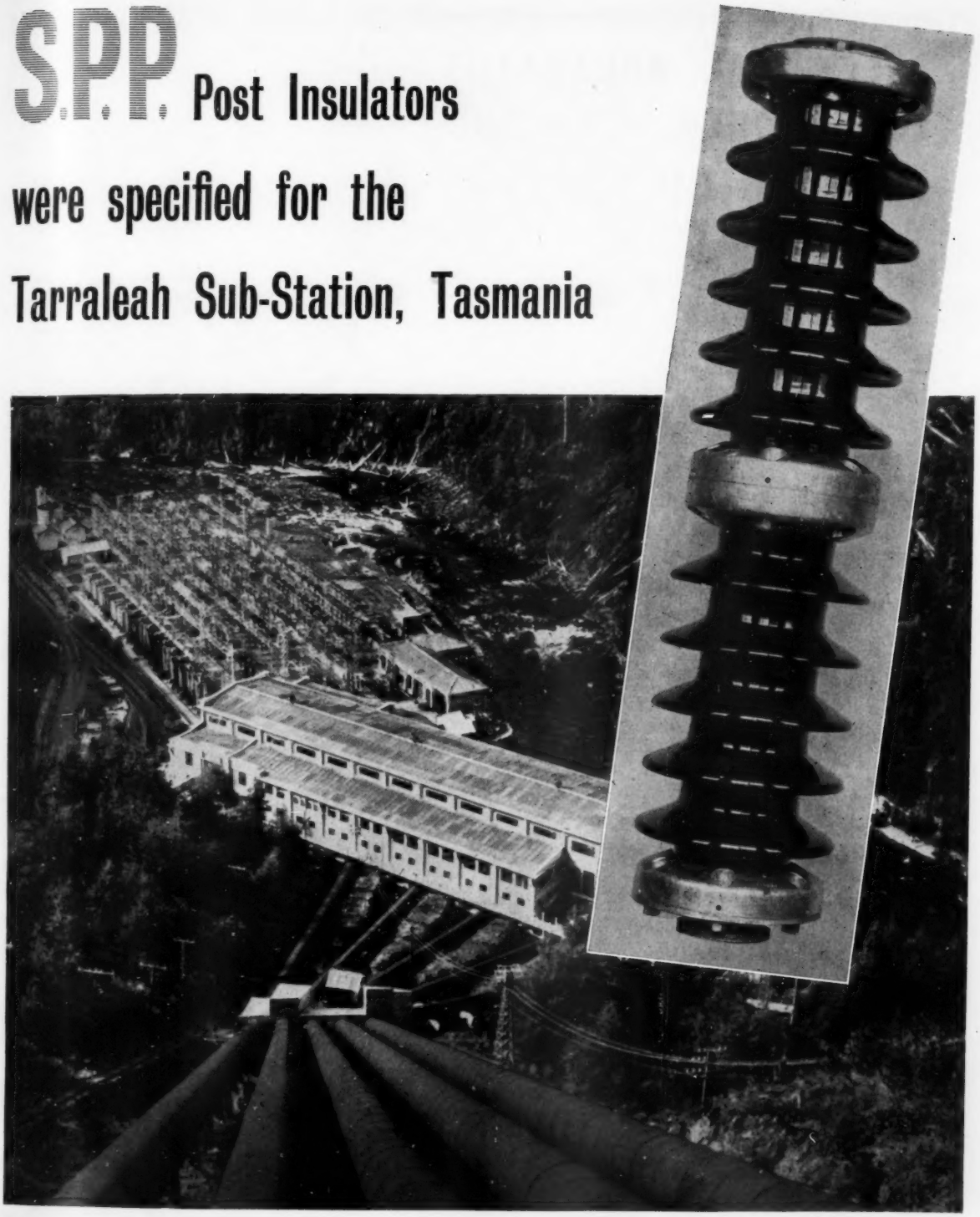

The Sub-station at Tarraleah, Tasmania, is one of the many 110 kV. and 88 kV. sub-stations on the Hydro-Electric Commission's system equipped throughout with S.P.P. Cylindrical Post Insulators.

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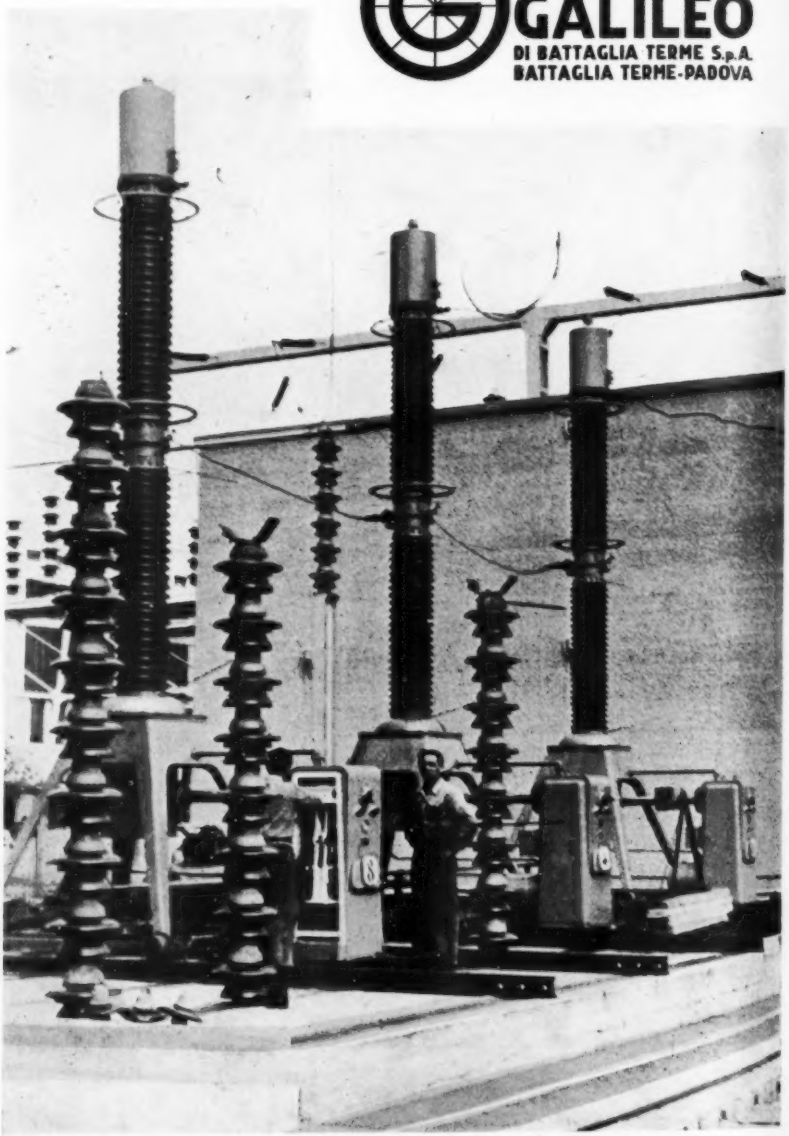

The illustration shows :
Switchgear type OCERD 220 photographed during a test for maximum load, made with favourable results at the test station of Messrs. Eléctricité de France at Fontenay aux Roses (Paris).

Specification of the switchgear :
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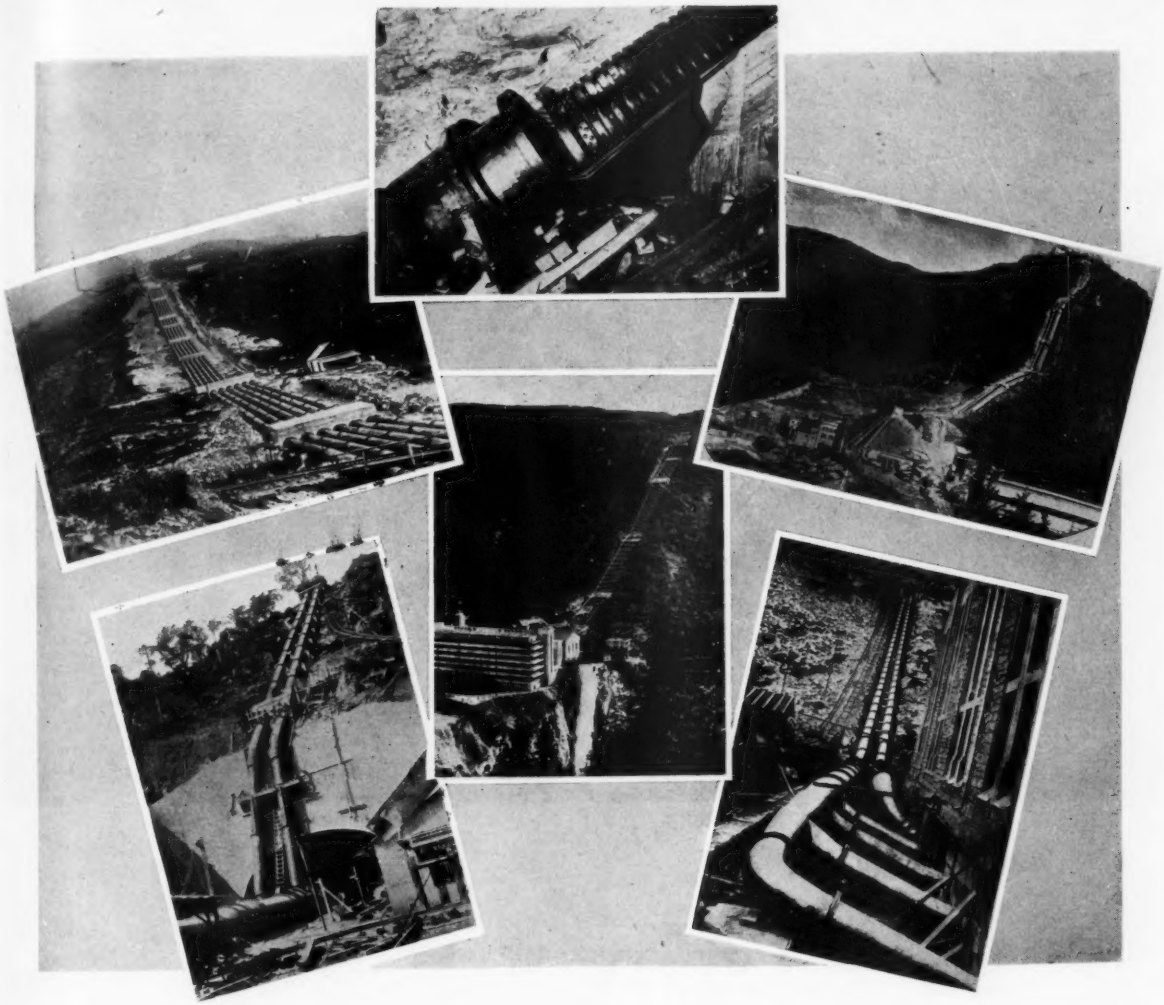

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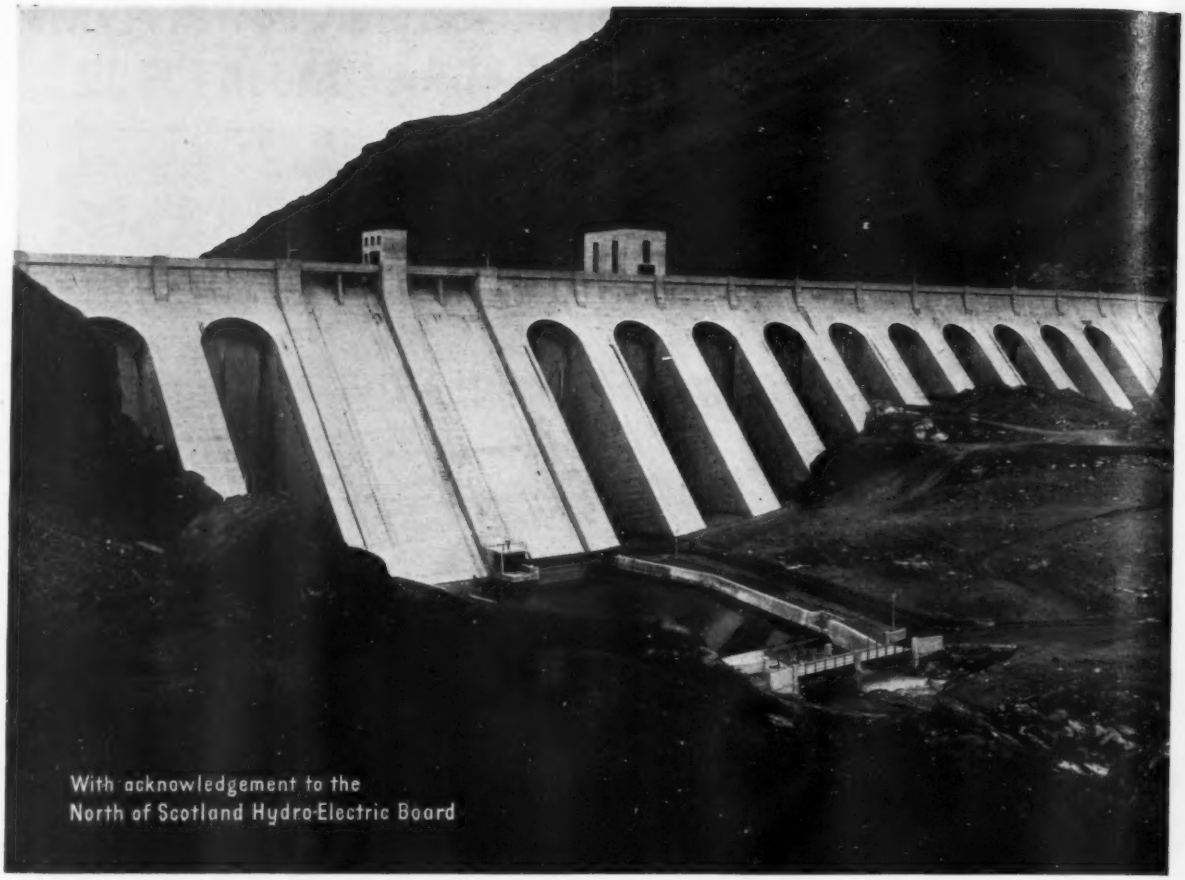

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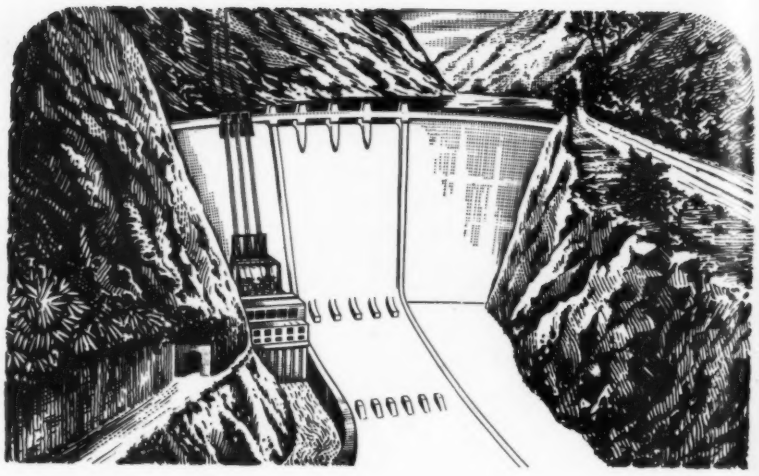

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Top: Artist's impression of the Los Peares Power Station, North-west Spain.

Left: Stator (under construction, in the BTH works) for one of the three vertical waterwheel-driven alternators (62,400 kVA., 11,000 volts, 3-phase, 50 cycles, 214 r.p.m.) to be installed in the above Power Station.

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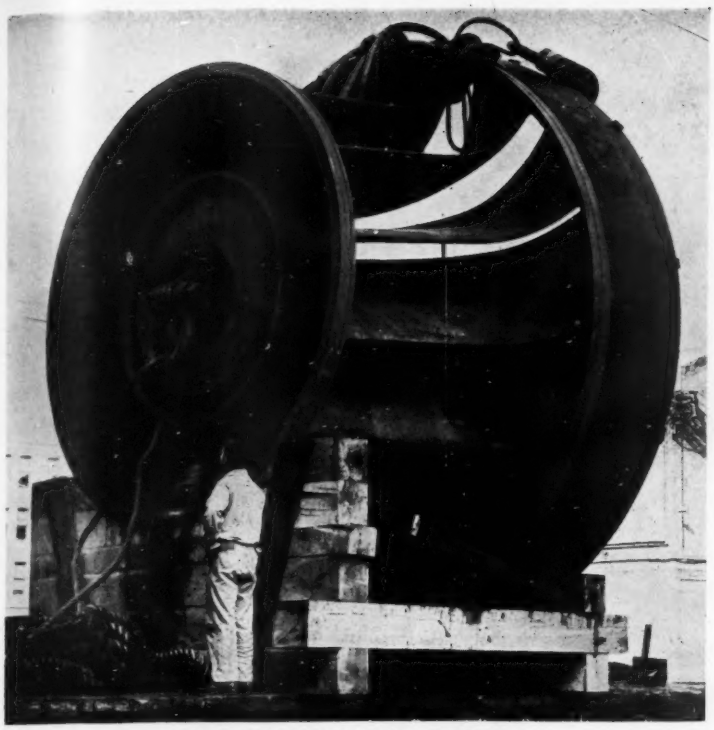

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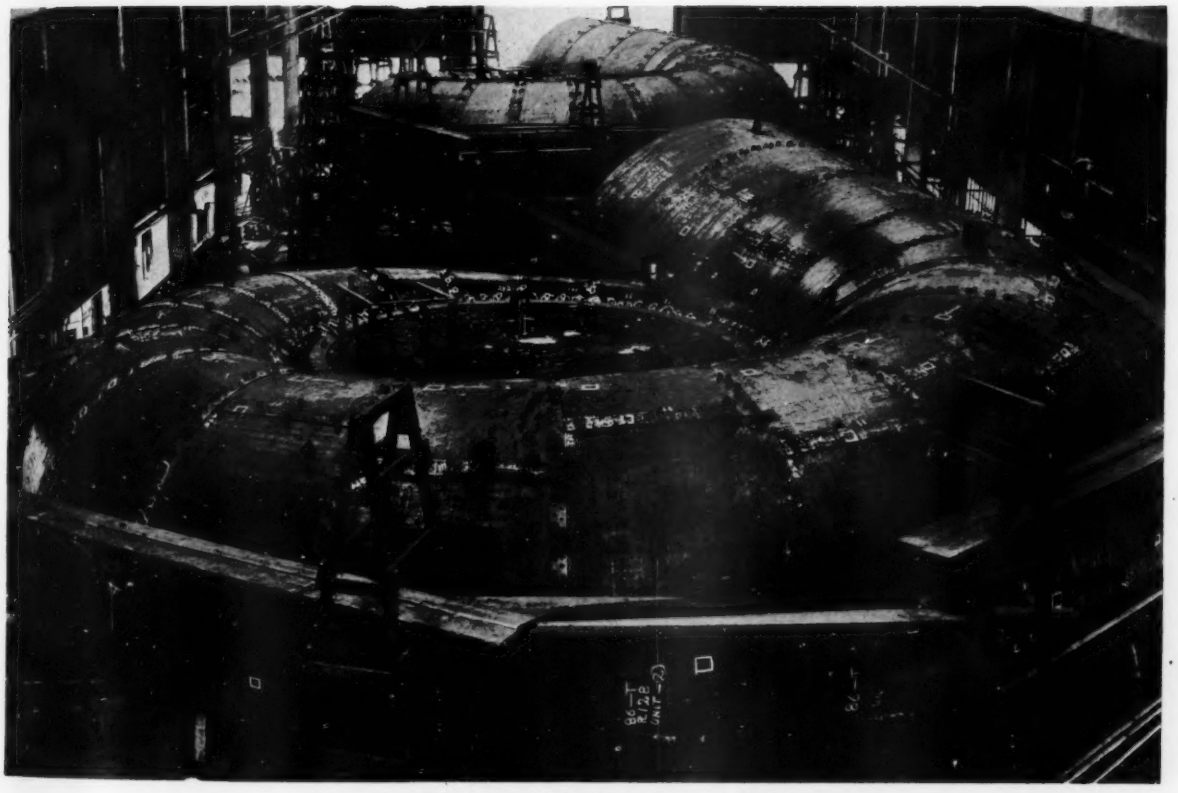

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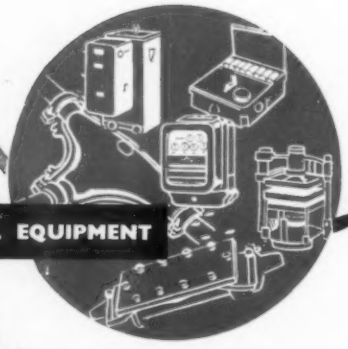

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Controlling Fish

THE North of Scotland Hydro-Electric Board have been experimenting for several years with electrical devices to direct fish into ladderways, and the results of experiments conducted at their Dundee laboratory, at dams in the Tummel Valley in Perthshire, and at the Morar hydro-electric station in Inverness-shire, were described at a meeting of the Royal Society of Edinburgh recently, the lecturer being Mr. Norman G. Lethlean, a technical and research officer on the Board's staff. Electrical methods were concentrated upon as it was found that sonic vibrations and lights of various colours proved to be quite ineffective. On the other hand pulsating electrical currents were astonishingly successful, particularly in preventing the ascending salmon and sea trout from swimming into the tailrace. With regard to the descending smolts the pulsating currents were not so effective in preventing entry into the turbine intakes, but the method nevertheless shows great promise. A device has also been installed to count the fish on their passage either upstream or downstream.

Mr. Lethlean claimed that these devices would both reduce the cost and increase the efficiency of the equipment normally used to prevent fish from entering unprofitable channels and directing them into the easiest route of travel.

Experiments were first carried out at Dundee to observe the reaction of trout to electric currents, and later an electric screen was erected at Morar. The equipment at Morar consisted of a row of aluminium electrodes each about 14 ft. long and extending to within 3 in. of the bottom of the channel, with two electrodes, about 16 ft. apart, placed 7 ft. downstream from the main row. A pulsating electricity supply was applied across the electrodes. This arrangement proved to be completely successful, all ascending fish being kept out of the tailrace and passing upstream to the entrance of the fish ladder. Salmon experienced obvious discomfort when about 5 or 6 ft. from the two outer electrodes of the screen, and, at that distance, turned and swam upstream past the end of the tailrace. Sea trout, apparently less sensitive, did not find the conditions too disagreeable until within 2 to 4 ft. (depending on their size) of the inner row of electrodes. What is important is that all the fish behaved in a perfectly normal way after leaving the electrified zone and there was no subsequent sign of distress or inclination to remain inactive.

The automatic electrical counter was designed by Mr. Lethlean and has been in operation at the dams at the Clunie and Pitlochry stations since the beginning of the salmon run in 1951. The counter was developed from the fundamental principle that there is a difference in the resistance to electrical current of salmon, or sea trout, and water. It consists essentially of an underwater electrical "bridge" which is influenced by the passage of the fish through the submerged orifice in the fish pass. Adjustments can be made so that only fish over a certain size are counted and refinements make it possible to operate the equipment in waters of widely varying chemical content. Separate dials record the passage of salmon going upstream and of kelts going downstream, and if a fish does not complete its journey through the orifice in the ladder, it is not recorded. Peat, leaves and other debris, such as logs of wood, milk bottles and empty food tins, thrown or washed from the river upstream, have not disturbed the dial readings. Daily checks during 1952 on the number of salmon and kelts observed to pass through the detector tunnel installed at Pitlochry have shown practically complete accuracy in recording fish. It may be said that the number of fish counted going up the ladder from April to the end of October 1952 was 5,697.

The experiments carried out with electric screens to divert descending salmon smolts were conducted above the dam at Dunalastair on the River Tummel in Perthshire. The purpose of these experiments was to prevent the smolts from entering the water within the vicinity of the mechanical screens at the intake to the aqueduct which conveys water to the Tummel Bridge power station and to divert them into the ladder. This screen consisted at the time of the experiments of two parallel rows of aluminium tubes strung diagonally across the lower end of the reservoir, the downstream row consisting of 272 tubes 1 ft. apart

and the second row, situated 6 ft. upstream, of 34 groups each 8 ft. apart. Electrical pulses were applied as in the case of the tailrace screen. Complete success was not achieved with this device but a large proportion of the smolts were diverted. In 1952, 70 per cent. of them used the fish pass instead of the alternative course through the electric screens, and as far as could be gathered, no injuries to the smolts could be attributed to electric shock at any stage in the experiments. These tests are now being continued with improved equipment in which some of the shortcomings of the original design have been eliminated. In view of the great expense involved in providing fine-mesh screens at intakes, the uneconomic size to which such screens have to be made to prevent the smolts being held against the bars, and the difficulty and expense of keeping the fine meshes clear, these experiments will be watched with a very great deal of interest.

The Kafue Gorge Project

THE report on the Kafue Gorge project, a summary of which we present elsewhere in this issue, has been unanimously accepted by the Northern Rhodesian Legislative Council. A motion by the Economic Secretary, Mr. R. A. Nicholson, has been approved which authorises the Government to procure the necessary funds for the scheme and to take all necessary steps to ensure its completion within the time specified by the consultants. It is the intention to proceed with both stages of the scheme, the first of which is estimated to come into commission in five years and the second stage in six and three-quarter years.

Progress at Owen Falls

THE Fifth Annual Report and Accounts of the Uganda Electricity Board refers to the fact that the present estimated costs of the Owen Falls scheme are approximately 100 per cent. higher than those given in the Project Report. The total direct cost, including provision for the civil-engineering works required to accommodate ten 15,000 kW generating sets, and the actual installation of six of these sets, is now estimated at £10,843,344.

Good progress was made during 1952. The rock-crushing plant for producing aggregate from local amphibolite, and the batching equipment used for concrete production, have continued to work satisfactorily and no serious difficulties have been experienced in turning out concrete of the quality required. By the end of 1952 total excavation work amounted to 317,000 cu. yards, while the quantity of concrete placed was 85,000 cu. yards. Crib placing for the second cofferdam for the main dam was completed early in May and the sheetpiling completed in August. A pocket of gravel in the south-east corner created sealing difficulties and as grouting was necessary some delay resulted in the dewatering operations. This was accomplished, however, early in November and the concreting for the sluice dam was begun a month later.

Preparations were well in hand at the end of the year for beginning the extensive concreting operations required for the dam on the east bank of the river. To enable this work to proceed before the upstream cribs are completed, a temporary gantry was built downstream of the dam to bridge the remaining gap of the Nile. Seven bays of the structural steelwork for the power house have been erected and concreting work, in its various stages, is now in hand for the first five generating sets; the excavation work for the remaining sets is also nearing completion. Other progress includes the erection of the 120 ton crane for the power house and the installation and testing of the No. 1 stayring. Plant continues to arrive on schedule.

Enquiries and negotiations conducted during the year, the Report states, give reason to believe that the whole of the power available will be absorbed by 1956-57.

Problems in Norway

OUT of a population of 3¾ millions in Norway, 3¼ million people are scattered about the country, living for the most part on single isolated farms, so that the supply of electricity to everyone is no easy matter, stated Miss M. B. Marris, senior demonstrator of the South Wales Electricity Board, when she presented the eighth Caroline Haslett Trust Lecture. The lecture was delivered at the Institution of Electrical Engineers, and was held under the auspices of the Electrical Association for Women.

Describing the appliances she found in the homes she visited, the speaker said that these varied somewhat from those in general use in Britain. There were not many highly loaded reflector type electric fires, as they were considered dangerous. Most of the all-electric homes had panel or skirting type heaters with a more even distribution of heat, and basic electrical heating was not allowed unless the best heat insulating material was used to prevent excessive losses.

Due to the type of country, interconnection of all power plants was impossible, although in some cases fjords had been crossed by spans of nearly two miles and in others by submarine cable. A number of the power lines had to be taken over barren mountainous tracks, and for these most of the erection work was done in winter as it is easier to transport over the ice and snow than over rough ground.

In Norway by 1951 the total installed capacity of 3,400 MW produced 17,500 million units, or 5,300 units per inhabitant. This high figure, reported Miss Marris, was very largely due to the great chemical and metallurgical industries which had been developed in recent years.

Tasmanian Expansion

IN the recently published report of the Hydro-Electric Commission of Tasmania for 1951-52, the Commissioners state that during the year 5,548 new consumers were connected in retail supply areas as compared with 5,792 during the previous year, although a reduction in the rate of connecting new consumers was expected, due in part to the falling off in the rate of building new homes. The number of units supplied by the retail supply branch was 383,330,442, an increase of 11 per cent. over 1950-51. This would probably have been 20 per cent. but for the restrictions on the use of electricity. The financial position, say the Commissioners, was, and

still remains, a difficult one. During the year they had requested the Hon. Treasurer to raise £7,193,000, compared with an expenditure of £5,705,000 in 1950-51, and later in the year had to make arrangements for a temporary advance against securities with the Commonwealth Bank of Australia. Some orders for goods and equipment had to be cancelled.

Assam Project

THE Umtry hydro-electric project in Assam, sponsored by the Government of India, will cost Rs. 15,000,000, according to the revised estimates. The previous estimate was Rs. 2,500,000. Recently, the Chief Minister of Assam said that the State Government were determined to complete the project as early as possible and that they would borrow whatever amount was needed to execute the first rural electrification scheme in the State. The Chief Minister also revealed that Canadian experts would visit the site and assist in the work.

Sweden's Expanding Output

A STATEMENT issued on behalf of the Power Board of Sweden indicates that in 1952 the total output of electrical energy increased by slightly over 5½ per cent., having risen from 19,400 million kWh in 1951 to 20,500 million in 1952. Of this only about 5 per cent. was generated by thermal means, the remainder having been derived from water power.

New Zealand Developments

POWER will be transmitted from the 320 MW Roxburgh (New Zealand) hydro-electric station by 220 kV lines transmitting at a substation to be built at Islington on the outskirts of Christchurch. A contract for the building of the substation has been let, through the Ministry of Works, to a Christchurch firm. On present plans, the substation will be completed in time to receive power from Roxburgh's first generators which the contractors aim to bring into operation in July of 1955.

Nairobi Delays

AT the annual meeting of the East African Power and Lighting Co. Ltd., a phenomenal growth of load in all areas of supply was reported by the chairman, Major C. M. Taylor. Last year he had expressed the hope that they would have overcome generating difficulties in Nairobi by the end of 1951 and that by June, 1952, they would be in a position to meet all their consumers' requirements. Unfortunately, that position had not been realised.

Delivery of the two 2,500 kW water turbines and alternators for the Wanjii development was only effected at site in mid-September, 1952, but their installation was now well advanced. Despite the delay in delivery and certain unexpected difficulties encountered in the civil engineering works, it was considered that the Wanjii development, of which the first 1,000 kW machine commenced operation in June, 1952, should be wholly available in early 1953. It did not appear that the complementary 2,400 kW set to be installed at the Tana power station, which would re-utilise the water diverted through the Wanjii scheme, could be in operation much before the middle of 1953. In regard to the year's operation the company and its two subsidiaries in Tanganyika sold 134·5 million units in 1951, as compared with 109 million in 1950, and received in payment £1,266,809 in 1951 as against £1,008,597 in 1950.

Milan Science Museum

TO meet a long-felt need in Italy and to celebrate, appropriately enough, the fifth centenary of that great pioneer of science, Leonardo da Vinci, a National Museum of Science and Technology has been founded in Milan. It is magnificently housed in the San Vittore monastery which has recently been reconstructed, with the most scrupulous care, to ensure that the entire block of buildings, in all details, shall conform to the original conception as closely as possible. The purpose assigned to the museum is defined as being to show progressively to what extent early technology survived up to the Middle Ages, to determine how much had been acquired at the time of Leonardo, to portray the contribution he made to so many fields of scientific endeavour, and finally, to continue the story of scientific and technical progress up to the present day.

On the recommendation of Dr. Carlo Rossi, one of the many prominent Italian scientists and technologists who have given unstinted support to the foundation, every endeavour will be made to present the exhibits in such a way that the observer will be able to "discover," as it were, for himself the significance of the step that was made by the original conception.

Good progress has been made in establishing a central library, in conjunction with which the Italian Technical Press Association has organised a room in which scientific and technical publications from all over the world are available to the public; and, of course, a wealth of exhibits has been donated by various organisations and individuals, the fascinating and almost incredible activities of Leonardo taking pride of place.

An interesting illustrated account of the museum by Guido Ucelli, head of the Riva concern, was published in *Rivista di Ingegneria* in the December 1952 issue.

Electric Energy from Yugoslavia

UNDER the aegis of the United Nations Economic Commission for Europe (ECE) a group of experts from Austria, Italy, Yugoslavia and the western zones of Germany, have agreed to study the possibility of exporting electric energy from Yugoslavia. The necessity to make a comprehensive investigation of the possibilities of exporting electric energy from Yugoslavia was approved by the Commission itself a year ago and since then the Commission has declared that it had now become of immediate importance and, indeed, a matter of *ad hoc* priority.

Information prepared by the ECE Secretariat and distributed in September last indicated that in hydro-electricity alone Yugoslavia possessed a potentiality of about 50,000 million kWh, of which only 3 per cent. was at present exploited. By contrast, the hydro-electric resources, for example, of Italy and western Germany, are both much more limited and much more fully exploited.

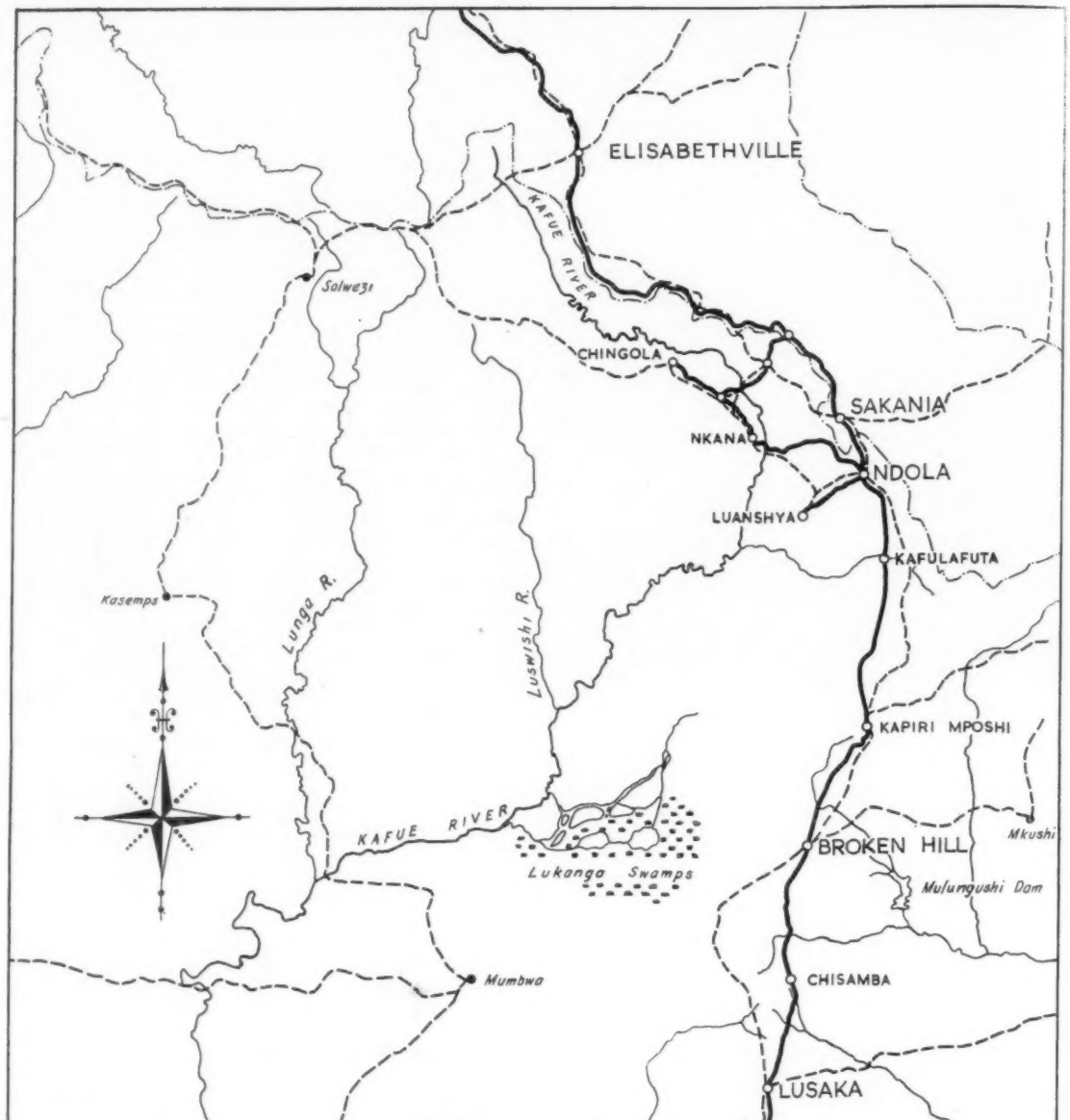

Fig. 1. Locality map showing the course of the Kafue River

Fig. 2. General view of Kafue Gorge from the north bank

The Kafue Report

Following our editorial last month announcing the publication of the report on the Kafue Gorge scheme we now give a detailed summary of the proposals.

AS explained in our leading editorial last month, the report on the Kafue hydro-electric project, which was presented to the Government of Northern Rhodesia on January 29, forms a sequel to the Kariba report presented to the Governments of both Northern and Southern Rhodesia in December 1950*, and has been prepared by the same panel of consulting engineers—Sir William Halcrow, Mr. Harold Gourley, Mr. C. H. Pickworth, and Mr. Geoffrey Kennedy.

The need for a fuller study of the potentialities of the Kafue was pointed out in the Kariba report, but the request for immediate investigation resulted from the power-supply demand developing in the Northern Rhodesian copper belt. It was seen that although Kariba possessed a much greater potentiality than Kafue, the situation in the copper belt was likely to become critical before Kariba could be in commission. In these circumstances the Government of Northern Rhodesia, in October 1951, asked for a report on the Kafue scheme, with the following terms of reference:—

(a) To ascertain whether or not a scheme exploiting the Kafue River at the gorge could be brought into operation to produce approximately 200 MW of firm power at an earlier date than that set by the Commission for the completion of the initial stage of the Kariba Scheme (1961).

(b) Any such project must be designed to become ultimately part of one using the full potential of the river and be capable of integration with any installation that may be set up at the Kariba Gorge on the Zambesi River.

Briefly, the consultants are unable to guarantee the production of 200 MW of firm power with the present proved storage facilities, but a conservative estimate indicates a figure of 186 MW at 80 per cent. load factor. They recommend a scheme based on a river

* See "Kariba's Part in Central African Development." WATER POWER, September 1951, page 324.

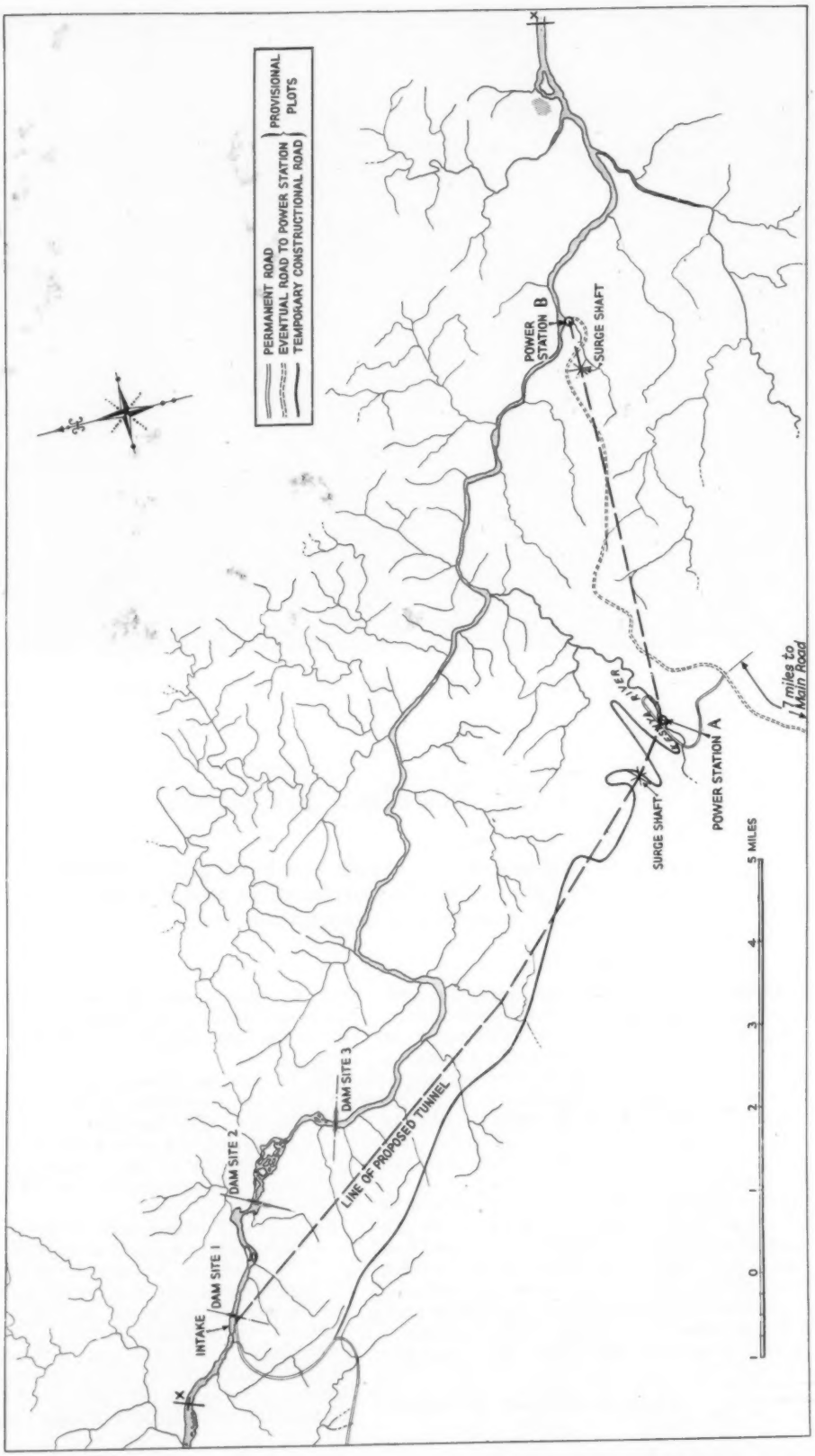

Fig. 3. Map of Kafue Gorge indicating the proposed development

discharge of 1,500 cusecs, giving 257 MW at 80 per cent. load factor with a utilisation of 99·4 per cent. Seeing that further investigations may show the resources to be greater than can as yet be relied upon, the scheme has been designed for a river discharge of 2,500 cusecs, equivalent to a capacity of 418 MW at 80 per cent. load factor, to which it can be increased by installing additional sets. Thereafter the installed capacity could be doubled, should conditions require it, by duplicating the tunnels.

The scheme would lend itself readily to interlinking with a development at Kariba, and in fact the linkage would benefit the combined undertaking.

Topographical and Hydrological Factors and Storage

The Kafue River (Fig. 1) is a tributary of the Zambesi, which it joins at Chirundu about 25 miles downstream of the Kariba Gorge. It rises on the frontier of the Belgian Congo, runs generally south until it is joined by the Lukanga, and then flows first westward and then southward to the Meshi-Teshi Gap. Thence it flows east for about 200 miles across a great flood plain, known as the Kafue Flats, to the Kafue Gorge where it falls about 1,900 ft. in a distance of 22 miles, emerging to flow a distance of about 25 miles across the Zambesi plain to Chirundu.

A map of Kafue Gorge, showing the proposed development, is given in Fig. 3, and a profile diagram of the river in Fig. 4. As will be seen from Fig. 4, the steepest descent occurs over a distance of 11·7 miles, the fall being 1,727 ft. Thus the gorge affords a promising site for power development, but it presents a difficult problem of storage. The storage within the gorge itself is inadequate for anything approaching full regulation, and to pond back over the Kafue Flats would create a vast shallow lake, the evaporation from which would be prohibitive. Meshi-Teshi Gap is a possible site for storage, but much investigation will be needed before it can be said how much of the regulated flow from this location would reach the Kafue Gorge. Other possibilities for storage are the lagoons on the Kafue Flats and the Lukanga swamp.

Three possible sites for a dam have been examined.

TABLE I.—COMPARISON OF DAM SITES

Site	Distance from road bridge	Dam		Length of tunnel saved	Extra storage
		length	height		
	miles	ft.	ft.	miles	acre ft.
1	13·8	600	100	0	0
2	15·2	1,390	130	1·0	15,000
3	16·9	1,320	300	2·25	35,000

They are indicated on Figs. 3 and 4, and are compared in Table I. Site 3 is economically impracticable on account of the great height and consequent cost of the dam. A dam at Site 2 would be over twice as long as a dam at Site 1 and would be 30 ft. higher; it would cost an additional £1½ million as against a saving of £½ million on the tunnel. The additional storage would not be sufficient to compensate for this extra outlay.

In the light of this comparison the site recommended is No. 1. The gorge is narrow at this point and consists of granite, which is exposed both on the river bed and on the flanks. Mr. W. H. Reeve, Director of the Geological Department of the Northern Rhodesian Government, has reported very favourably on the geological aspects of this site.

It is proposed that the dam shall be of the concrete buttress type with drum gates on the right flank to pass flood water. The crest level will be 3,215 ft. O.D. and the normal retention level 3,200 ft. O.D. After the peak of the flood has passed the water level will be allowed to rise to about 3,205 ft. O.D., with a maximum limit of 3,210 ft. O.D. It is estimated that a net effective storage of 100,000 acre ft. can be relied upon and it may be greater.

One of the major difficulties confronting the consultants was the paucity of hydrological data. Regular readings of the height of the river at the railway bridge at Kafue have been taken since 1905, but no discharge measurements were taken until 1946, when a gauging site was selected just below the site of a road bridge subsequently constructed some seven miles downstream from the railway bridge. Daily readings of the river height at the road bridge were not commenced until 1948. Rating curves for the road bridge site have been drawn by the Water Development Department from observations taken since 1946, but this information needed to be correlated with the railway-bridge river-height readings before use could be made of the 47 years of records at the railway bridge.

A straight-line correlation was made by Mr. F. S. E. England, the hydrological engineer to the Inter-Territorial Hydro-Electric Power Commission, based on readings taken from May 1948 to July 1949. A second correlation was made by Brig. Hawes in his report on the Kafue River in 1951, his curve being practically a straight line above 3,200 ft. O.D. The two curves cross at 3,209 and 3,194·20 ft. O.D., Brig. Hawes' curve being the lower between these two levels. A detailed study by the Water Development Department showed that in each of the four hydro-

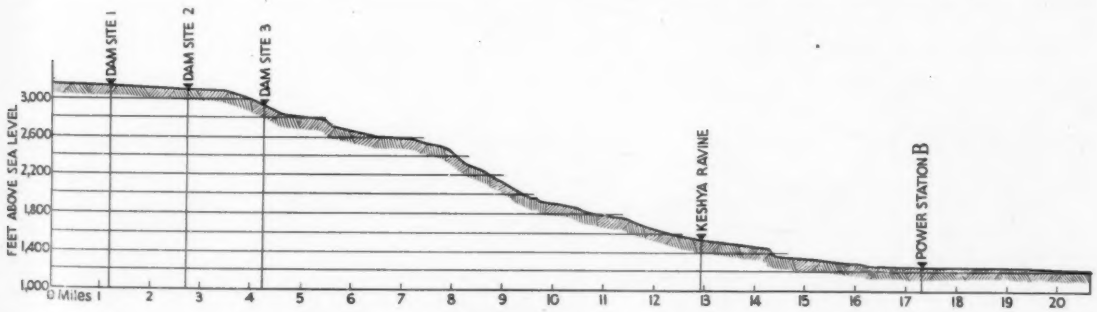

Fig. 4. Profile diagram of Kafue Gorge showing alternative dam sites

Fig. 5. Kafue Gorge looking upstream from dam site

logical years between 1948 and 1952 the curve for rising flood was invariably above that for falling flood, due, it was thought, to the growth of sudd and weed below the railway bridge, this growth being washed away by a high flood. On this basis the Department drew two rating curves, for rising and for falling flood respectively, and interpolated a mean curve.

With this information at their disposal the consultants have made their own study, using the road-bridge rating curves to plot the railway-bridge readings against the relevant discharges, and made the further discovery that the difference between the curves of rising and falling floods was very slight in low floods but increased with floods of higher intensity. As a result of this study they have drawn the curves shown in Fig. 6, consisting of a single curve for rising and falling floods up to 6,000 cusecs, and separate rising and falling curves for floods of 18,000 and 42,000 cusecs. A comparison of the results obtained by the use of these curves with the direct readings available since 1948 shows a much closer correlation than by other methods.

This study has enabled tentative discharge figures to be assessed from the railway-bridge records, but as the storage for the proposed scheme will be limited it was necessary only to consider the dry years. These are set out in Table II together with the firm available discharge with various amounts of storage. The figures

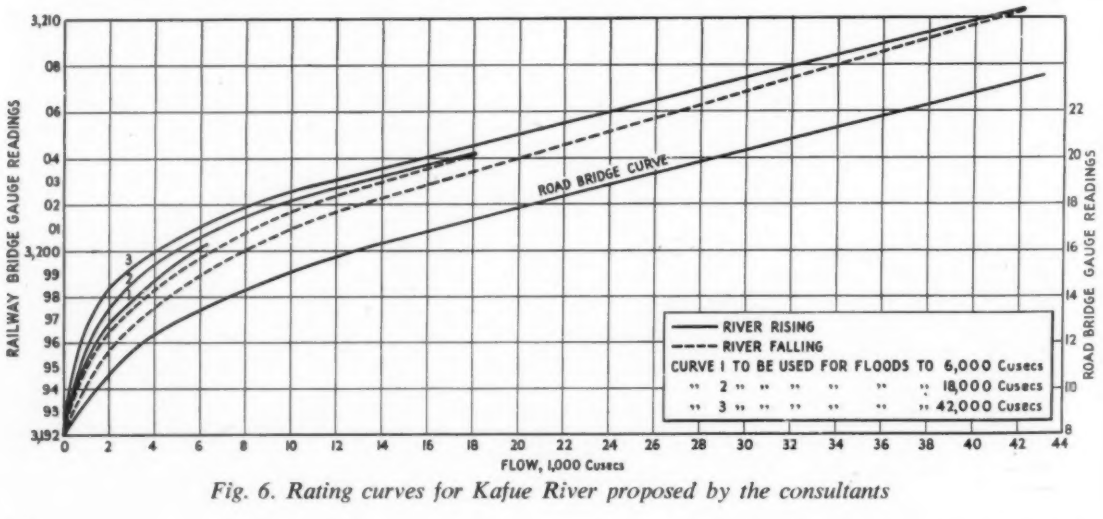
RAILWAY BRIDGE GAUGE READINGS
ROAD BRIDGE GAUGE READINGS
FEET ABOVE SEA LEVEL
FLOW, 1,000 Cusecs
ROAD BRIDGE CURVE
RIVER RISING
RIVER FALLING
CURVE 1 TO BE USED FOR FLOODS TO 6,000 Cusecs
" 2 " " " " " " 18,000 Cusecs
" 3 " " " " " " 42,000 Cusecs

Fig. 6. Rating curves for Kafue River proposed by the consultants

Fig. 7. Kafue Gorge looking downstream from dam site

for 1949-50, which are abnormally low, are regarded as suspect especially as there was a large flood during the preceding year which may have scoured out the channel, leaving passage for a greater flow than that indicated by the levels.

TABLE II. FIRM AVAILABLE DISCHARGE (CUSECS) FOR VARIOUS AMOUNTS OF STORAGE

Storage (1,000 acre ft.)		50	75	100	125	150
1	1949-50	462	583	682	781	880
2	1915	858	979	1,078	1,166	1,254
3	1946-47	963	1,080	1,200	1,310	1,400
4	1918-19	1,078	1,188	1,320	1,408	1,518
5	1924-25	1,144	1,254	1,364	1,441	1,518
6	1909-10	1,122	1,298	1,441	1,562	1,672
7	1928-29	1.194	1.353	1,474	1,592	1,683

Better correspondence exists between the figures for the other years tabulated, and it is felt safe, and indeed conservative, to take 1915 as determining the firm power available. An analysis of shortages for various draw-offs and storages indicated that a considerably larger capacity of plant should be installed than that required for firm power, and as already indicated, one suitable for a draw-off of 1,500 cusecs is recommended. If a seasonal variation of load is permissible, a much larger output could be obtained during at least half the year, and a plant for 2,500 cusecs would be justified.

Layout of the Scheme

From No. 1 dam site to a suitable power-station site at the foot of the steepest part of the gorge involves about 13½ miles of tunnel and renders available a mean gross head of 1,936 ft. It is impracticable to utilise this head in a single stage because the ground in the vicinity of the station site is not sufficiently high to permit the construction of a surge tank at the requisite elevation, and the nearest high ground would involve four miles of unregulated tunnel.

To meet this difficulty a two-stage scheme is proposed, an intermediate station being located in the Keshya ravine—a steep valley formed by a tributary of the Kafue. The point in the ravine at which this station should be sited is determined by the economic balance of the scheme. If the station were placed close to Kafue Gorge the outputs of the upper and lower stations would be about 202 and 55 MW respectively, and the cost of power from the lower station would be more than that from the upper, but as the site is

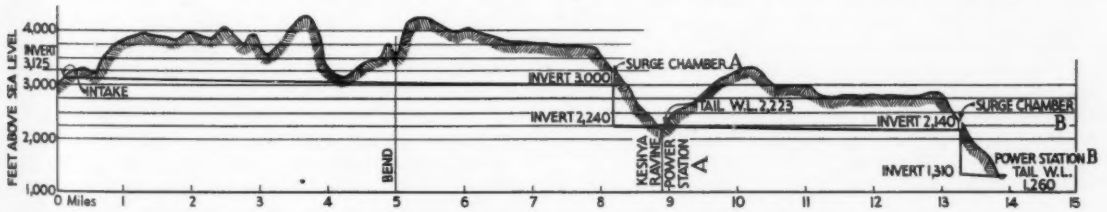

Fig. 8. Profile diagram of the proposed development

moved up the ravine a point would be reached at which the costs of energy from the two stations would be equal. At this point the output of the upper station would be somewhat less than that of the lower, because the upper station has to bear the cost of the dam and of a longer tunnel, but considering the scheme as a whole the most economical arrangement is obtained when the heads, and consequently the outputs, of the two stations are equal. Under this condition the plant for the two stations can be made identical, thus simplifying operation, facilitating maintenance, reducing spare parts, and probably reducing the cost of the plant and time of delivery. Furthermore, a site higher up the ravine will be more accessible and the weir needed to pick up the water for the lower station will probably be shorter.

The alternative of placing the intermediate station in the Kafue Gorge was considered, but the inaccessibility of the site and the size of the pick-up weir were found to militate against it. A further alternative considered was a single-stage scheme with an underground station below the Keshya ravine, with a tailrace tunnel some four miles long, but such a scheme might take about eighteen months longer to bring into operation.

A profile diagram of the proposed scheme is given in Fig. 8. An intake on the right-hand flank of the gorge just above the dam will lead to a concrete-lined tunnel 20 ft. in diameter and 8½ miles long leading to the upper station. The invert of the intake will be at 3,125 ft. O.D. and will descend at about 1:300 to the surge shaft, which will be extended as a vertical downtake shaft leading to a short horizontal tunnel with a separate branch to each turbine. A weir across the Keshya ravine will divert the tailwater into a similar tunnel, five miles long, leading to the lower station in the Kafue Gorge.

The tunnel has been designed for a regulated flow of 1,500 cusecs, at which the total loss will be less than 2 per cent. of the gross head, and could accommodate flows up to 2,500 cusecs, when the loss would be under 5 per cent. Should a still larger flow be required a second upper and lower tunnel would be driven alongside the first, and to enable this to be done without emptying the reservoirs it is proposed to construct the intakes for the second tunnels in readiness.

Power Stations and Switchgear

As already explained, the generating plant will be distributed equally between the upper and lower stations and will be designed to give a supply of 257 MW at 80 per cent. load factor, provision being made for extension to 418 MW with the single tunnels and for the addition of further plant capacity with double tunnels. These data, together with considerations of transport and spares, have led the panel to recommend the installation of four 43 MW sets in each station, one set in each station being a spare. Vertical-shaft Francis turbines are recommended, running at 428 or 500 r.p.m. and coupled to 11-15 kV alternators. Auxiliary power would be derived from a 1,500 kW Pelton-wheel generator in each station, the auxiliary switchboards of the two stations being connected by an 11 kV overhead line.

The output from both stations will be controlled from a double-busbar central outdoor switching station. To reduce the cost of high-voltage switchgear it is proposed to connect the alternators in pairs to three-winding step-up transformers, generator switching being on the low-voltage side and busbar switching on the high-voltage side. For reasons of transport each step-up transformer will consist of a bank of three single-phase units, the duplicate lower-voltage windings of each unit being rated at 15 MVA and the higher-voltage windings at 30 MVA. One single-phase unit will be carried as a spare.

The generator circuit breakers should have a rupturing capacity of 750 MVA and the high-voltage breakers should be rated at 5,000 MVA to allow for future interconnection with Kariba.

Transmission

The Electricity Development Committee have tentatively proposed the following distribution of the available power:—

To the mines in the copper belt ...	100 MW
To their adjacent townships and N'Dola	15 MW
To the Lusaka/Chilanga area	15 MW
To Southern Rhodesia	100 MW

A transmission voltage of 220 kV is regarded as the most suitable. This is the voltage proposed for the supply from the Belgian Congo to the copper belt, and for the Kariba scheme the optimum voltage range was considered to be 220 to 275 kV. In the case of Kafue there appears to be no justification for 275 kV, and 220 kV would seem the best suited to meet the overall situation.

Single-circuit overhead lines, each about 220 miles long and running north and south respectively, are considered sufficient to carry the required loads, the Lusaka/Chilanga area being supplied from a receiving station connected to the main transmission line to the copper belt and N'Dola from the receiving station in the copper belt. Sufficient generating capacity will be held in the copper belt to supply essential loads in the event of interruptions of supply, and it is believed that the same will apply to Southern Rhodesia, so that a double-circuit construction does not appear to be necessary.

Steel-cored aluminium single conductors of 0·4 sq. in. equivalent copper section are recommended, carried on steel towers designed for a wind loading of 12 lb. per sq. ft. Insulation should be not less than 1,050 kV on the basis of a one-fiftieth microsecond wave. Lightning conductors should be installed at each substation on all incoming lines, and a second series should be situated about half a mile from each substation where local conditions make it desirable.

Substations of 120 MVA capacity will be located at N'Kana in the copper belt and at Norton in Southern Rhodesia. Each will have a 40 MVA synchronous condenser, and the N'Kana substation will also handle the supply from the Belgian Congo. The circuit breakers should be rated at not less than 3,500 MVA. At each station the step-down transformer will consist of a bank of three single-phase units, and a spare unit will be carried. A 20 MVA three-phase transformer will handle the supply tapped off for the Lusaka/Chilanga area.

Construction Time and Cost

In computing the construction time the largest undertaking to be taken into account on the civil-engineering side is the tunnel. It will be driven from

(Continued on page 150)

Fig. 1. The Snowy Mountains from Geehi

Snowy Mountains

In this series of articles we recount the history of this huge Australian multiple-purpose project, discuss its technical and economic background, describe the proposals now adopted by the Snowy Mountains Hydro-Electric Authority, and relate the progress made by the Authority in implementing the scheme.

PART ONE

THE Snowy Mountains scheme, in the Australian Alps, ranks with the T.V.A. development as one of the largest multiple-purpose projects in the world. Its effect on Australian economy cannot fail to be profound, for it will make a major contribution to three of the country's vital economic needs, viz., power, food, and the conservation of coal. The ultimate generating capacity is expected to be three million kilowatts, which is more than the total installed capacity in Australia today. For irrigation purposes the scheme will supply an additional 2,300,000 acre-feet of water per annum to the Murray and Murrumbidgee Rivers—a quantity estimated to increase the value of Australia's food production by no less than £25 million per annum. The saving in black coal is expected to rise to an ultimate figure of four million tons per annum, together with the labour involved in mining and transporting it.

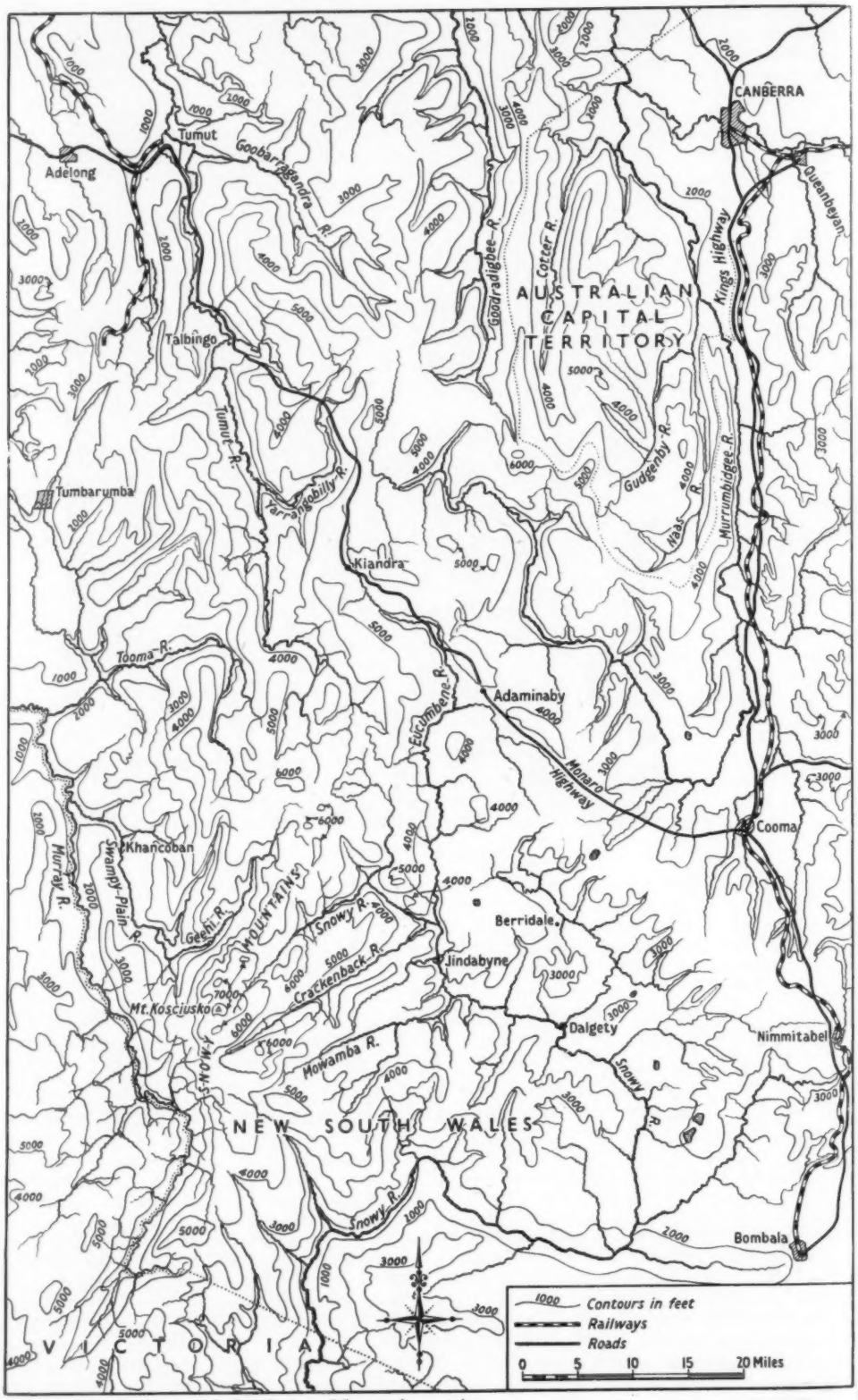

Fig. 2. Contour map of the Snowy Mountains region

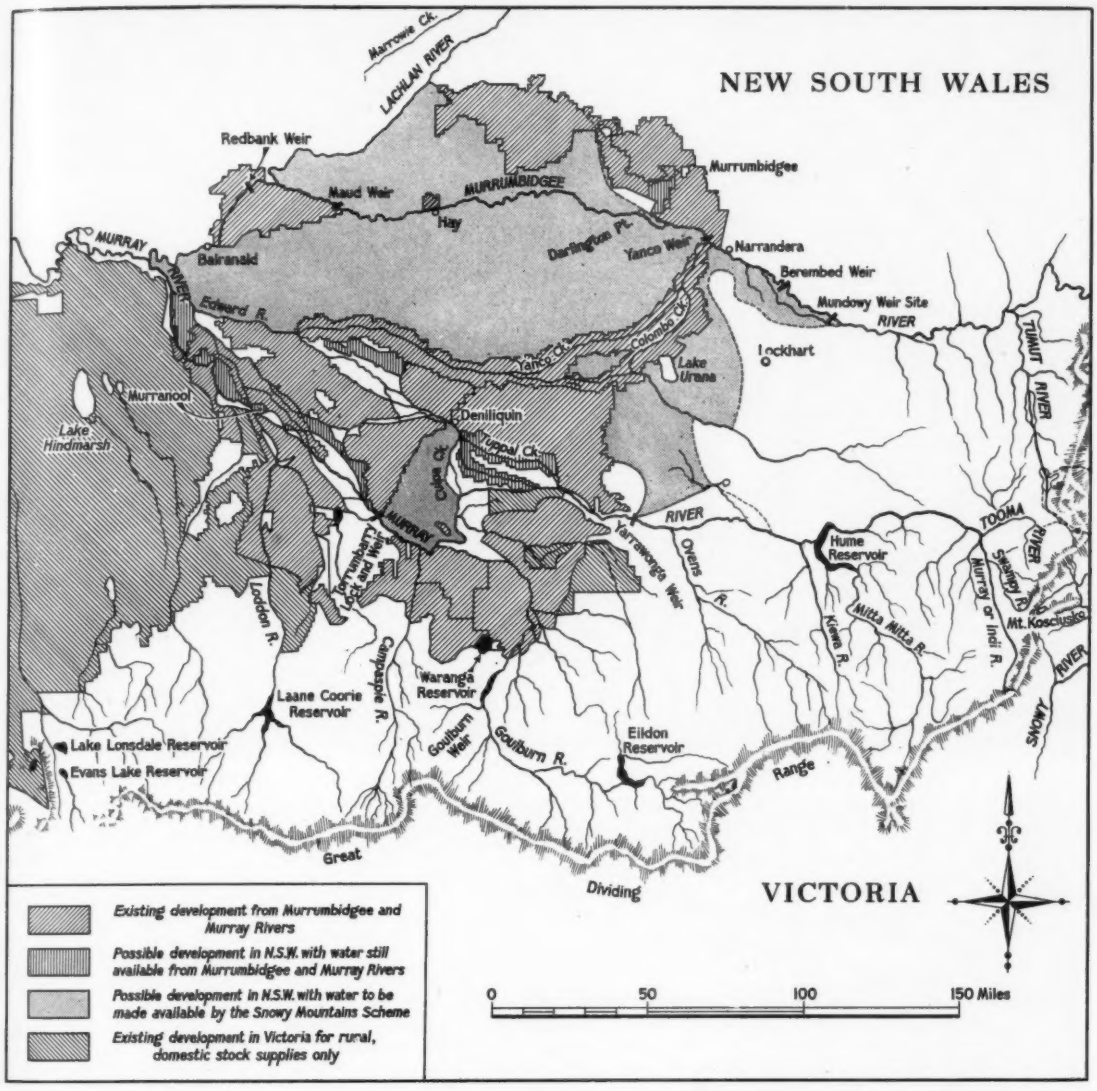

Fig. 3. Irrigation map of the area to be served by the Murrumbidgee and Murray Rivers

Unlike many schemes the economic justification for the Snowy development does not depend on these indirect gains, for it is regarded as financially sound on the score of electricity production alone. Estimates based on 1948 construction costs placed the annual operating cost, including interest and sinking fund, at £6 million. The corresponding annual cost of operation of modern thermal plant of equal capacity using black coal as fuel was calculated to be £15 million, giving an estimated saving of £9 million per annum. In other words the generating cost will be well below half that of thermal generation.

The complete scheme will involve the construction of seven major dams, 16 power stations, 86 miles of large-diameter tunnel, nearly 500 miles of racelines along the mountainsides to pick up streams at high elevation and lead their waters to reservoirs and tunnels, many miles of roads in mountainous country and a number of subsidiary works. Preliminary estimates based on 1948 costs place the overall cost at about £225 million, including nearly £100 million for transmission lines. Nevertheless, the work is not just a long-term project, for the first power—from Guthega—will be produced in 1954, and during the succeeding five years the generating capacity coming into service is expected to be as given in Table I. Water will also become available in stages, and by

TABLE I

Estimated dates when projects will produce power	Firm power added MW
1954	60
1957	120
1959-1960	480
Cumulative Total	660

Fig. 4. Looking north-west from the summit of Mount Kosciusko

Fig. 5. Upstream view of the Guthega dam site in winter

Fig. 7. The Snowy River at Jindabyne, showing Nos. 2 and 3 dam sites

1958 the Murrumbidgee valley should benefit by an additional flow of 500,000 acre-feet per annum, which will more than double the total quantity of water at present diverted annually for irrigation in this valley. Of the 2,300,000 acre-feet of water which the scheme will provide ultimately, 1,400,000 acre-feet per annum will go to the Murrumbidgee and 940,000 acre-feet to the Murray.

Topography

Australia is part of a great plateau of Archean rocks, much of which has been above sea level throughout Palaeozoic and later times and has been reduced for the most part to a barren rocky peneplane. On the edges of the continent, however, there has been a certain amount of building up by moderate folding, which is most pronounced along the east coast, parallel to which is the Great Dividing Range, reaching a maximum height of over 7,000 ft.

As might be expected, the area of greatest rainfall lies between this Range and the Pacific coast, whereas on the western or inland side precipitation is very light. This limited rainfall combines with the small area at high elevation to give a comparatively low hydro-electric potential to the mainland as a whole, but there are regions in the Great Dividing Range where hydro-electric generation may make a substantion contribution to the country's economy. In northern and central Queensland, where the Tully Falls and Burdekin schemes have been investigated, the rainfall ranges up to 200 in. per annum and the heights reach four to five thousand feet, but the areas at high level are comparatively small, and the projected developments are only 92,000 kW for Tully Falls and 42,000 kW for Burdekin. In northern New South Wales extensive investigations into the potentialities of the Clarence River system have shown that an ultimate development up to 400,000 kW may be possible. In Victoria the principal project is the development of the Kiewa, a tributary of the Murray, which is expected to have an ultimate capacity of 289,000 kW at a total net head of 4,200 ft.

As will be evident, however, from the figures we have quoted, by far the greatest potentiality is available in the Snowy Mountains area which lies partly in Victoria and partly in New South Wales. It lies conveniently near to Canberra and is about midway between the two main load centres, Sydney and Melbourne, being about 250 miles from each. This region contains Mt. Kosciusko (7,328 ft.) the highest point in the Australian Alps, as well as several other peaks over 7,000 ft. high, there being more than 40 square miles lying above 6,000 ft. The western escarpment is steep, giving a rapid fall to the 1,000 ft. level at the Swampy Plains and the Tumut valleys. On the eastern side the slopes are more gradual, the main outlet below 1,000 ft. being the valley of the Snowy River.

These features will be evident on reference to the map of the area given in Fig. 2, and the river system can be followed with the aid of this map and of the irrigation map, Fig. 3. The Murray River, lying on the western side of the Range, rises at the southern extremity of the area and flows north, being joined successively by the Swampy Plains River (fed in turn by the Geehi River) and the Tooma River. Thence it

turns west and finally enters the Southern Ocean east of Adelaide.

The Murrumbidgee River rises in the northern part of the area and flows south-east, then turns north near Cooma, and ultimately turns west. Of its various tributaries the most important in the Snowy Mountains area is the Tumut River, which rises in the centre of the area and flows down the western escarpment in a northerly direction. Later the Murrumbidgee is joined by the Lachlan River and finally flows into the Murray.

The Snowy River is the only one in the system which does not turn inland to the western side of the Range. It rises near Mt. Kosciusko and receives the largest share of the run-off, finally flowing south through eastern Victoria to the Tasman Sea. Of its tributaries the chief is the Eucumbene, which rises between the Tumut and the Murrumbidgee but flows south.

Precipitation is estimated to be over 120 in. per annum on the highest points of the area, but the intensity falls away rapidly to the east; official figures give 89 in. at Charlotte Pass, 3½ miles east of the highest point of the divide, 48 in. at the Hotel Kosciusko, about 7 miles east, and only 21 in. at Jindabyne, 16 miles east of the divide. The peaks are snow covered for five or six months of the year, affording a heavy run-off during the summer months when it is most needed.

Seeing that the Snowy River rises in the highest part of the Australian Alps and runs steeply through fertile country, it is not surprising that it has attracted attention both as a source of power and as a source of irrigation water to be diverted to the dry side of the Great Dividing Range. We shall explain these proposals, together with the scheme fully adopted, after describing the present position in respect both of irrigation and of power supply.

Agricultural Development and Irrigation

From an agricultural standpoint the greatest area of good soil in Australia lies in a broad belt stretching from Queensland to Victoria and lying to the west of the Great Dividing Range. It is watered by the largest river system in the Australian mainland—that formed by the Murray and its tributaries the Darling, Lachlan, Murrumbidgee, Gouldburn and other streams.

In New South Wales the area that will benefit from the Snowy Mountains scheme lies east of the confluence of the Murrumbidgee and the Murray near Balranald and west of a line running north from the Hume reservoir on the Murray to Mundowy weir on the Murrumbidgee. This includes an area extending about 25 miles north of the Murrumbidgee and from Narrandera on the east to the Lachlan River on the west. There are also some smaller areas lower down the Murray.

The soils are almost wholly alluvial, and as would be expected from the method of formation, the coarser, more permeable red-brown earths occur in the east towards the source of the system, but become very fine towards the west, where they form heavy clays. The red-brown earths occur in two fairly well-defined forms, coarser deposits being found near the beds of the old streams, and finer deposits in the intermediate plains. These soils form a basis for the successful irrigation settlements in Victoria and New South Wales, the coarser channel deposits, in particular, being capable of high production. To the west, the fine-grained grey and brown soils are in many instances high in gypsum and salt content, but where they were formed along the banks of the streams they are generally of high fertility.

The areas are all of low rainfall, ranging from about 20 in. in the east to about 10 in. in the west. The summers are hot and dry, and the winters cold and dry with widespread frosts.

During the twelvemonth July 1, 1949, to June 30, 1950, New South Wales diverted a total of 870,000 acre-feet for irrigational, domestic and stock-supply purposes, 580,000 acre-feet being derived from the Murrumbidgee and 290,000 acre-feet from the Murray.

On the Victorian side of the Murray valley the soils and meteorological conditions are very similar to those in the New South Wales Area. In the Goulburn valley portion the soils are slightly acidic and are of the red-brown earth variety, whereas to the west are the heavier grey and brown soils of the Loddon valley, which merge into the Mallee red-brown sands and sandy loams in the north-west of the State.

The rainfall ranges from 10 to 20 in. as in the corresponding area in New South Wales, and there is no appreciable run-off except close to the Dividing Range, where the annual rainfall rises in places as high as 60 in. Average summer temperatures range up to 85-90°F.

Much of this area is already irrigated, and during the twelvemonth July 1, 1949, to June 30, 1950, Victoria diverted 1,310,000 acre-feet from the Murray and its tributaries.

The map in Fig. 3 shows the areas in both New South Wales and Victoria that are served with water from the two rivers, and also those areas which it may be possible to develop with water made available by the Snowy Mountains scheme. All the new areas to be considered for development lie in New South Wales, whereas in Victoria it is proposed to devote the additional water to more intensive development of areas already served.

Power Supply

The conditions of power supply in New South Wales and in Victoria are sharply contrasted. New South Wales possesses ample reserves of good-quality easily won black coal within easy reach of Sydney. The total installed thermal capacity in the State is about 790 MW, including about 30 MW of diesel plant, to which must be added about 32 MW of hydro power. Owing to the war this represents a lag in installation of some 225 MW, and it is estimated that an additional 1,280 MW will be required within ten years. Approvals have already been given for an additional 740 MW.

In Victoria, on the other hand, deposits of black coal are very limited and of comparatively poor quality, whereas brown coal, having a calorific value of about 3,000 B.Th.U. per lb., is available in thick beds at shallow depths. Hydro-electric potentialities, too, are not so remote from the load centres. Thus the power-supply system is built up on three types of plant. The base load is carried by steam stations situated in the brown-coal fields; seeing that these are

Fig. 8. Typical mountain country in the Tumut area, with Mount Bogong in the background

plants of high capital cost but use cheap fuel it is economical to run them at high load factor. Peak loads are met by steam stations located near the load centres and burning higher-grade and more costly fuels such as briquetted brown coal, imported black coal and fuel oil. Between these two types the hydro-electric stations fill in the intermediate portions of the load curve to provide the best economic balance. The extent to which they operate depends on water availability, and advantage is taken of any surplus reserve to reduce the consumption of the expensive fuels in the metropolitan steam stations.

The State Electricity Commission's system in Victoria has a generating capacity of some 504 MW, comprising 185 MW from brown-coal plants, 267 MW from metropolitan stations, and 52 MW from hydro-electric plants, and an ultimate capacity of 1,246 MW is envisaged apart from any contribution from the Snowy scheme.

To sum up, the value of the Snowy Mountains scheme to Victoria lies primarily in its power potentialities, whereas its value to New South Wales lies primarily in the supply of water for irrigation. It is not surprising, therefore, that the original schemes put forward by the two States were conflicting, leaving a situation that was brilliantly resolved by the Technical Committee set up by the Premier's Conference in 1947. The history of these earlier proposals and the manner in which the present scheme was finalised is of interest.

History of the Scheme

Proposals to utilise the water resources of the Snowy Mountains Area were made as early as 1884 and have been put forward on many occasions since that date. Most of the early schemes centred around water for irrigation, but between 1915 and 1918 the New South Wales Department of Public Works carried out surveys with a view to using the Snowy River for the generation of electricity for Sydney and the south-east region of the State. This project did not contemplate the use of water for irrigation and was considered solely from the aspect of production of power, the total amount of which was estimated at 150 MW.

In the early and middle twenties other proposals were put forward, including one for the supply of water to Sydney and some country towns. In 1937, the former hydro-electric scheme of 1918 was revived and elaborated by two Swedish engineers engaged by a firm of British consulting engineers acting for the New South Wales Government. The estimated capacity of their proposal was approximately 250 MW, that is, 100 MW greater than the 1918 scheme, but

Fig. 9. The township of Adaminaby with part of the water storage area in the background

less than one-tenth that of the present Snowy Mountains scheme.

All these proposals had in mind regional interests rather than the full utilisation of the water resources of the area in the interests of the nation as a whole.

Later, in 1944, a Special Committee appointed by the New South Wales Government carried out further investigations on the possible use of the Snowy River and stressed the need to divert the water inland to the Murrumbidgee for irrigation. However, the Commonwealth had certain rights conferred by the Seat of Government Acts, and Victoria also was concerned. The lower reaches of the Snowy River pass through Victoria, and a Victorian engineer drew attention to the fact that by diverting the Snowy into the Murray, not only would its waters be available for irrigation but also the power output would be considerably greater than from any of the earlier schemes considered by New South Wales.

The commencement of effective action came for the first time in 1946 when Ministers of the Commonwealth, New South Wales and Victoria, with their technical advisers, met to discuss the future of the Snowy waters. Thus for the first time the use of this river was discussed from the national viewpoint, and, in addition, due attention was given to its complete usage for both power and irrigation. New South Wales representatives at the conference strongly advocated the use of the Snowy for irrigation by diverting it into the Murrumbidgee. Victorian representatives, however, advocated diversion to the Murray as this would provide much more power, in addition to water for irrigation.

This important conference ended with an agreement that an investigation into the two alternative proposals, namely diversion to the Murrumbidgee and diversion to the Murray, should be carried out by the Commonwealth. The engineering aspects were made the responsibility of the Department of Works and Housing and the agricultural and economic aspects were handled by the Department of Postwar Reconstruction. Both Departments were assisted in their investigations by the New South Wales and Victorian State Government Services and by experts from other Commonwealth Departments.

The result of this Commonwealth examination showed that the proposed diversion from the Snowy to the Murray was not only practicable but was also extremely attractive from the viewpoint of production of power. A monetary advantage which could be capitalised at over £40 million was indicated for the Murray proposal. The agricultural and economic investigation, however, found that from the viewpoint of irrigation the proposal to direct the waters to the Murrumbidgee Valley possessed advantages.

As already mentioned, a Premier's Conference in 1947 considered the power and irrigation reports and recommended fuller investigation. For this purpose, a Technical Committee under the chairmanship of Dr. L. F. Loder, Director General of the Commonwealth Department of Works and Housing, with representatives from the Commonwealth, New South Wales and Victoria, was set up. The main function of the Technical Committee was to obtain the necessary information so that a decision could be made as to which of the rival schemes should be adopted.

The Committee extended its investigations to cover the whole of the Snowy Mountains Area, and in its first report of November, 1948, showed that the poten-

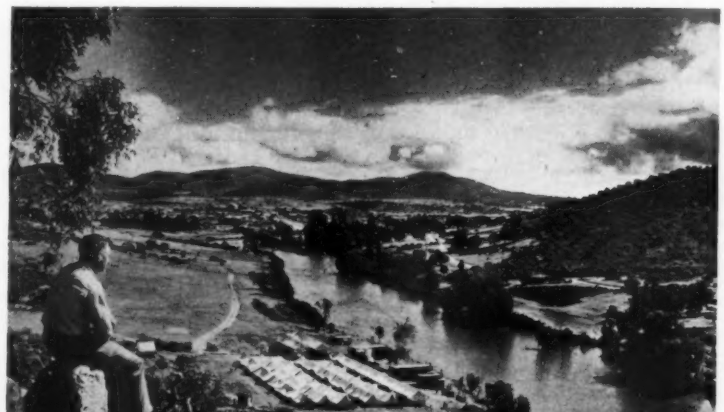

Fig. 10. Advance camp on the bank of the Snowy River at Jindabyne

tial value of the waters of the Snowy Mountains is very much greater than previously appreciated. It recommended that neither of the previously considered alternatives be adopted, but that another proposal providing for the diversion of a substantial proportion of the headwaters of the Snowy, the Murray and the Murrumbidgee Rivers to the Tumut River should be proceeded with as soon as possible, and that further investigations should be carried out before a decision was made in regard to the use of the remainder of the Snowy flow.

The value of this recommendation lay in the fact that effective use would be made of the head down to the 1,000 ft. level so that as a power proposition it ranked with the Victorian proposal for diversion to the Murray; on the other hand the Tumut would discharge the waters to the Murrumbidgee Valley where they were most needed for irrigation. This recommendation was approved by Ministers representing the Commonwealth and States of New South Wales and Victoria in February 1949.

The Technical Committee's second report, recommending that the balance of the Snowy River waters should be diverted to the Murray instead of to the Murrumbidgee, was presented in June 1949. This report covered the full range of the Committee's investigations, which extended far beyond a specific comparison of the two alternative schemes, and included an examination of the water resources of the whole Snowy Mountains area. This examination brought out the great significance of the scheme and lifted it to a level of one of major national importance, both from the irrigation and from the power development aspects.

Ministers of the Governments of the Commonwealth, New South Wales and Victoria met in Canberra in July 1949 and approved the Committee's recommendations. To give effect to the proposals and so enable the extensive water resources nature has provided in the Snowy Mountains Area to be developed for the use of the nation, the Commonwealth Parliament passed the Snowy Mountains Hydro-Electric Power Act, 1949, establishing the Snowy Mountains Hydro-Electric Authority, which came into being on August 1, 1949.

The Authority is constituted by a single Commissioner, assisted by two Associate Commissioners. Mr. W. Hudson, previously Engineer in Chief, Sydney Metropolitan Water, Sewerage and Drainage Board, was appointed Commissioner, and the two Associate Commissioners were Mr. T. A. Lang, previously Commissioner of Irrigation and Water Supply, Queensland, and Mr. E. L. Merigan, previously Electrical Engineer, State Electricity Commission, Victoria.

(To be continued)

A Wind Power Development

In 1949 the British Electricity Authority invited tenders for the design, manufacture, testing and setting to work of an experimental wind-driven electrical generator of 100 kW capacity. It so happened at that time that Enfield Cables Limited were studying the economics of wind power as a source of heat for horticulture, but the B.E.A. invitation led to a revision of this policy and it was decided to make an attempt at the major plant. By a process of elimination it was finally decided that the "depression" principle, which had been tested on a small scale by Andreau in France, offered, on balance, the best practical advantages on which to work. Although the Andreau system did not offer an energy conversion efficiency as high as more orthodox plants of equal size, and the cost of development would be higher, its physical and mechanical advantages were deemed to outweigh all other considerations even in a relatively small plant of 100 kW capacity, whereas with larger plants these advantages would be substantially increased.

It will be recalled that in the depression system there is no mechanical connection between the propeller and the generating equipment, this link being afforded by a partial vacuum formed in the hollow blades of the propeller, the inrushing air driving an air turbine situated at ground level and directly coupled to a generator. In the unit constructed by the Enfield Company the generator is a 100 kW 415 V 3-phase synchronous induction machine, with exciter, which is started from rest as an induction motor. When the synchronous speed is approached direct current is fed into the field thus causing the generator to operate as a synchronous motor running under no load conditions. Air is then admitted to the turbine which in turn drives the "motor" in synchronism with the connected system. The pitch of the propeller blades is adjusted automatically, by hydraulic means, so that the rotational speed is maintained constant when the wind speed is in excess of 30 m.p.h.

It is understood that trials on the equipment are to be made in the immediate future and that these will be followed by tests under light inland breezes. Throughout the design and constructional period Enfield Cables Limited have had the co-operation of de Havilland Propellers Limited and the English Electric Co. Ltd., the tower itself having been built by the Redheugh Iron and Steel Co. Ltd. to de Havilland design.

Electricity Tariff Handbook, compiled for *Electrical Review* with the advice and assistance of V. A. H. Clements, M.I.E.E. Published on 25th February, 1953, by Electrical Review Publications Limited, and distributed by Iliffe & Sons Limited. Price 7s. 6d. 8½ in. × 5½ in. 64 pp.

This reference book, compiled with the advice and assistance of the Assistant Commercial Manager of the British Electricity Authority, gives full details of the standard tariffs in operation in England, Scotland and Wales by the various Area Electricity Boards. The classes of tariff shown are: Domestic, Commercial (Block type and Maximum Demand type), Industrial (Block type and Maximum Demand type), Farm and Miscellaneous. For ease of reference, a tabular summary of each class is provided. The B.E.A. bulk supply tariff is also shown.

Air Compressors. The Atlas Diesel Co. Ltd. of London have sent us a copy of a handsome brochure they have issued relating to the various types of air compressors they manufacture. This publication is essentially of a technical nature and gives a great deal of useful information to users and potential users.

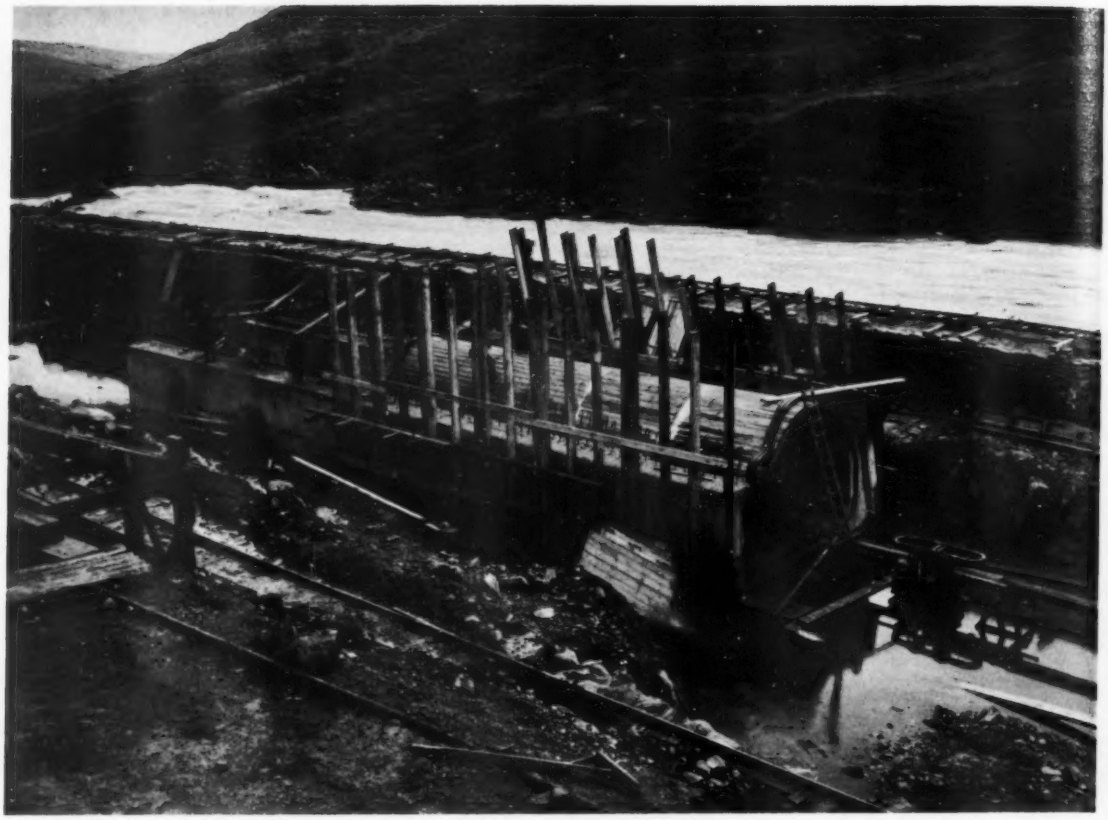

Fig. 1. Concreting of south culvert, Quoich dam

The Garry Project

In this article preliminary particulars are given of this scheme, with particular reference to the civil-engineering works.

THE Garry Project of the North of Scotland Hydro-Electric Board develops the River Garry in Inverness-shire. The development is in two stages, namely the upper, or Quoich works, and the lower, or Invergarry works, both of which are at present under construction. When complete the project will have an installed capacity of 42,540 kW which will give a total estimated output of 168·4 million kWh per year.

Quoich Works

The Quoich dam forms the main storage reservoir of the project and is of rockfill construction with a reinforced-concrete upstream sealing membrane. Rockfill for the dam will be obtained from a quarry near the dam and from the Quoich tunnel excavation, and will be placed in the dam in 2 ft. deep layers, consolidated mechanically and washed with water to obtain maximum compaction. An upstream membrane was adopted in preference to a central core wall so that the maximum structural use could be made of the fill, and because it was considered that any maintenance required on the dam would be simplified. The membrane will be formed in 20 ft. by 20 ft. reinforced-concrete slabs, 15 in. thick at the deepest section of the dam and 12 in. thick for the remainder. The joints between the slabs will be sealed by copper strips filled with a bituminous compound, and are designed to accommodate the movements anticipated in the rockfill. Two culverts will be built at the base of the dam. One will have a free rolling type gate at the upstream end and housed in a tower, access to which will be by means of a 120 ft. span footbridge from the crest of the dam, while the discharge will be controlled at the downstream end by a 72-60 in. needle valve. A branch from the 6 ft. pipe in this culvert will feed the 200 kW turbo-alternator to be housed in a small station at the foot

of the dam. The flow through this turbine will serve as compensation water required under the scheme. The other culvert will be closed by a blank flange and a single-faced sluice and used only at low water levels. A spillway 305 ft. long will be formed on the left bank of the reservoir, immediately upstream of the dam, and flood water will be returned to the river through a concrete-lined channel.

As the top water level of the reservoir is above the level of the divide between the catchments of the rivers Garry and Carnach, two short mass-gravity concrete dams will be constructed at the lowest point of the divide.

Upstream of the Quoich dam is the intake to the Quoich tunnel formed by a deep approach cutting, and across the tunnel portal are screens which can be raked. A short distance downstream will be a vertical shaft which will house two gates to be manufactured by Glenfield and Kennedy Ltd. The downstream gate will be permanently housed just above the soffit of the tunnel and normally used for closing the tunnel, whereas the upstream one will be kept in the gate house at the top of the shaft and lowered only when the downstream gate has to be inspected or when it will not operate.

Fig. 3. Invergarry dam site after drawing down the loch

Between the intake and the surge shaft the tunnel is horseshoe in cross section, of 11 ft. 6 in. equivalent diameter, concrete lined throughout and 14,500 ft. long. The surge shaft is 174 ft. deep, the top 40 ft. being 50 ft. in diameter and the remainder 30 ft. At the bottom of the surge shaft a 158 ft. deep, 11 ft. 6 in. diameter shaft will lead the water into the high-pressure tunnel, which is 2,100 ft. long. Up to 1,222 ft. from the station the internal water pressure will be resisted by the concrete lining of the tunnel and the surrounding rock. Downstream of this point steel pipes surrounded with concrete in tunnel and trench will be used.

The generating station will house a 22 MW horizontal-axis Francis turbo-alternator in a machine room 40 ft. high, 73 ft. 6 in. long and 49 ft. wide. The gross head on the turbine will be 320 ft. The station will be founded on rock, the superstructure will be a steel-frame building with masonry walls. Only a small control room and office accommodation will be provided.

Fig. 2. Bottom heading at portal of Quoich tunnel

Invergarry Works

About 10 miles downstream of the Quoich generating station will be the Invergarry dam which will be sited in a gorge. A 24 ft. equivalent - diameter concrete-lined diversion tunnel, 618 ft. long, has been driven to divert the river during construction. When the dam has been completed the tunnel will be used to lead flood water away from a 174 ft. long spillweir. The dam will house two 10 by 15 ft. gates, which can be

raised to pass floods or provide artificial spates when required under the scheme. A Borland type fish lock will provide a route for salmon and also assist in the descent of kelts and smolts. The compensating water will be discharged from the dam through one 75 kW and one 265 kW turbo-alternator.

The intake to the Invergarry tunnel will be fitted with screens with the apertures small enough to prevent smolts being drawn into the tunnel. Work on the conduit between the intake and the station is being undertaken in five sections all with a cross-sectional area equivalent to a 16 ft. 6 in. diameter circle. The low-pressure section is 14,800 ft. long, horse-shoe shape in section and concrete lined, the high-pressure shaft being 91 ft. deep and circular in section, as also is the 800 ft. long length of tunnel between the shaft and the steel pipes (460 ft. long), leading into the station. The surge shaft is of the differential type, 96 ft. deep, with a 14 ft. 6 in. internal-diameter riser inside a 60 ft. diameter shaft.

Fig. 4. Invergarry diversion tunnel, looking downstream

A 20,000 kW Kaplan turbo-alternator operating under a gross head of 175 ft. will be installed at the Invergarry generating station. The machine room will be a deep pit on the north side of the Inverness—Fort William road, and the draught tube will be formed in a tunnel under the road, discharging into the River Garry through screens to prevent salmon from entering the tailrace. The machine chamber will be 60 ft. high from the turbine floor to the roof, 80 ft. long and 52 ft. wide. The control room, transformer and switching yard will be adjacent to the main road. As the rock is not of very good quality a concrete lining will be used and a cavity left between the concrete and the brick panel walls to collect any water which may seep through. Above ground the structure will be faced with masonry.

Progress on the Quoich Scheme

The contract for the construction of the Quoich dams and tunnel was awarded, in May 1951, to Richard Costain Ltd. The camp and workshops have been erected. At the Quoich dam excavation of soft material overlying the rock is in progress. Cofferdams for the river diversion are being built, as also are the two culverts. A total of 2,382 ft. of the low-pressure portion of the tunnel has been driven, 829 ft. from the tunnel intake and 1,553 ft. from an adit driven near the surge shaft. The tunnel for the high-pressure pipes has been driven and 1,147 ft. of the high-pressure tunnel. At the surge shaft a pilot shaft is being excavated by means of a Calyx drill and is at present 77 ft. deep.

The contract for the construction of the Invergarry dam and tunnel was let in May 1951 to Whatlings Ltd., the contract for the construction of the Invergarry generating station being subsequently let to the same firm.

Camps and workshops have been erected and at the Invergarry dam the diversion tunnel has been driven. Excavation in the spillway channel is being carried out prior to diverting the river by a cofferdam. The intake gate shaft has been excavated and is used for raising the muck from the tunnel. The section of the tunnel upstream of the gate shaft has been excavated and 1,300 ft. has been driven towards the surge shaft. A further 4,000 ft. of the low-pressure tunnel has been driven from an adit. A pilot hole has been sunk by a Calyx drill at the surge shaft which is now being opened out to full size. In the

(Continued on page 145)

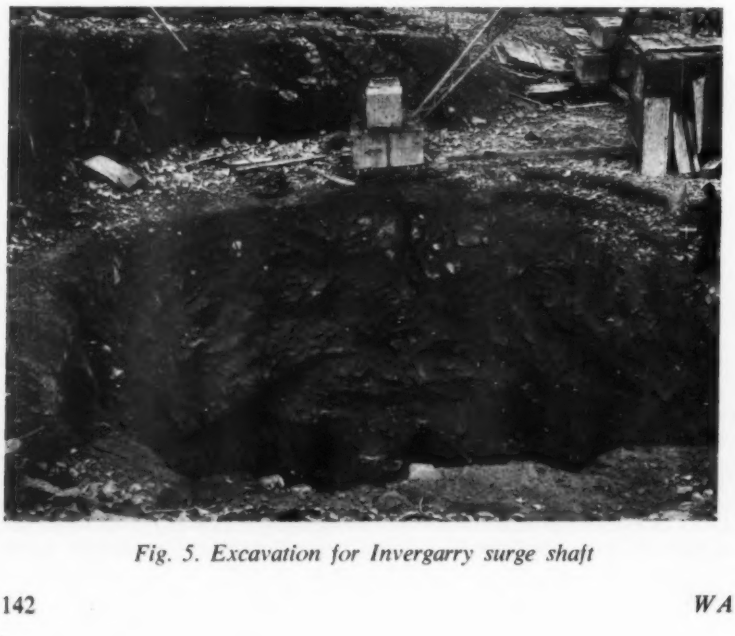

Fig. 5. Excavation for Invergarry surge shaft

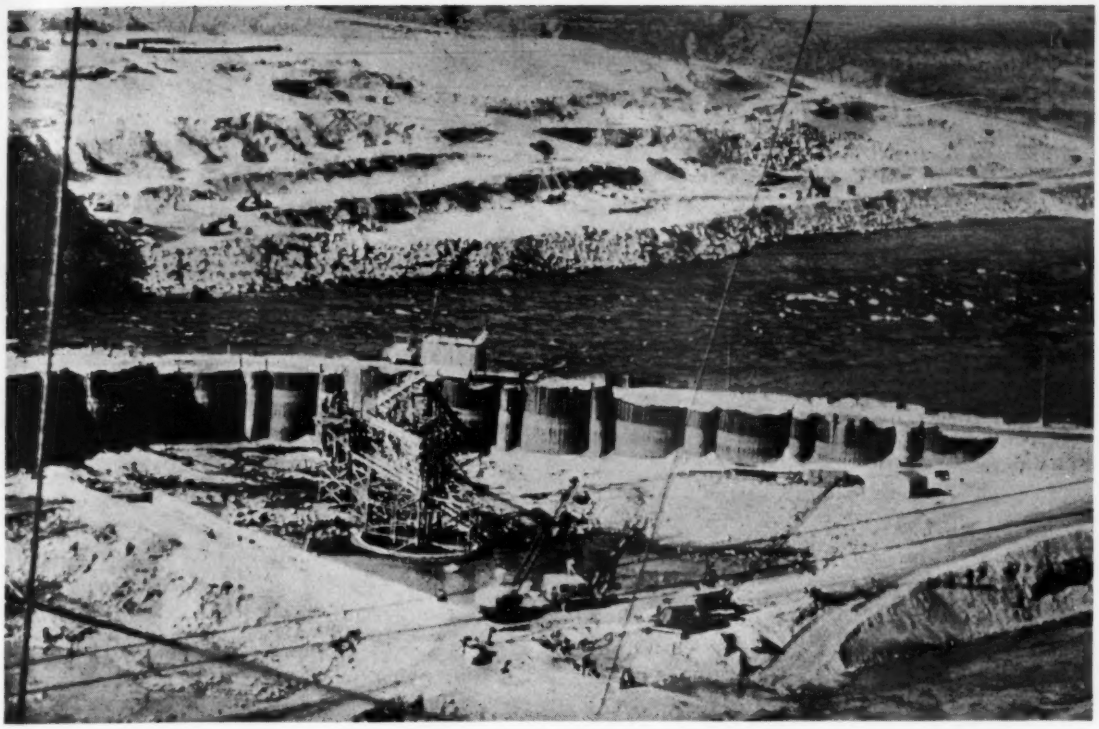

Fig. 1. First-stage cofferdam under construction

The Chief Joseph Dam

Ice is used in the mix to cool the concrete for the dam to serve the world's second largest water-power plant.

By NORMAN CLARKE JONES,
A.M.C.T., M.I.Chem.E., M.Inst.F.

ON the Columbia River, 1½ miles east of Bridgeport, Washington, U.S.A., a large dam is being constructed to form a reservoir which will extend 51 miles upstream to the tailrace of the Grand Coulee power station. This new dam, the "Chief Joseph," has been named after a notable Nez Perce chief who for a time fought successful actions against United States troops but was finally overcome and allowed to end his days peacefully, in 1904, not without honour.

In order to man the Chief Joseph project permanent houses are being erected at Bridgeport, and new main sewers, water-pumping plant and reservoirs are being constructed to improve the amenities. The storage lake will have an area of 7,150 acres and the dam will be a concrete gravity-type structure 220 ft. high with a spillway section 922 ft. long, the total length of the dam being 2,450 ft. The intake canal will be 3,000 ft. long, 30 ft. deep and 1,000 ft. wide. The flow over the spillway will be controlled by 19 tainter-type crest gates, 40 ft. wide and 38·5 ft. high, and capable of passing 1·25 million cu. ft. per second when fully open. A steel bridge, on which a movable crane will operate for servicing the gate machinery and for general maintenance, will surmount the dam, and a 22 ft. wide roadway will be provided for vehicular traffic.

The intake construction and power house, which will require 800,000 cu. yards of concrete, extend downstream at an angle to the dam and will rest on solid granite some 50 ft. below the river surface. The power house will be 2,036 ft. long and provided with 27 generators each with a rating of 64,000 kW, giving a total of 1,728,000 kW for the complete installation. It is expected that four units will be in operation by the end of 1955, and 16 by December, 1958. The first four generators have been ordered from the Westinghouse Electric Company at a cost of £1,520,000; for

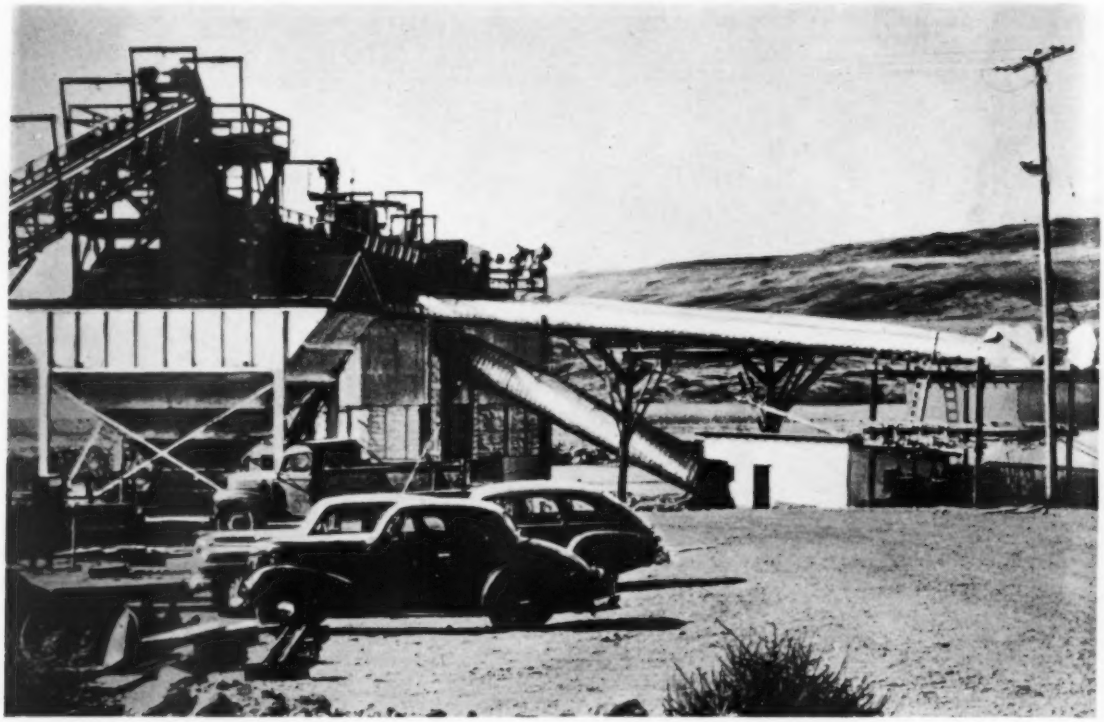

Fig. 2. General view of batching plant

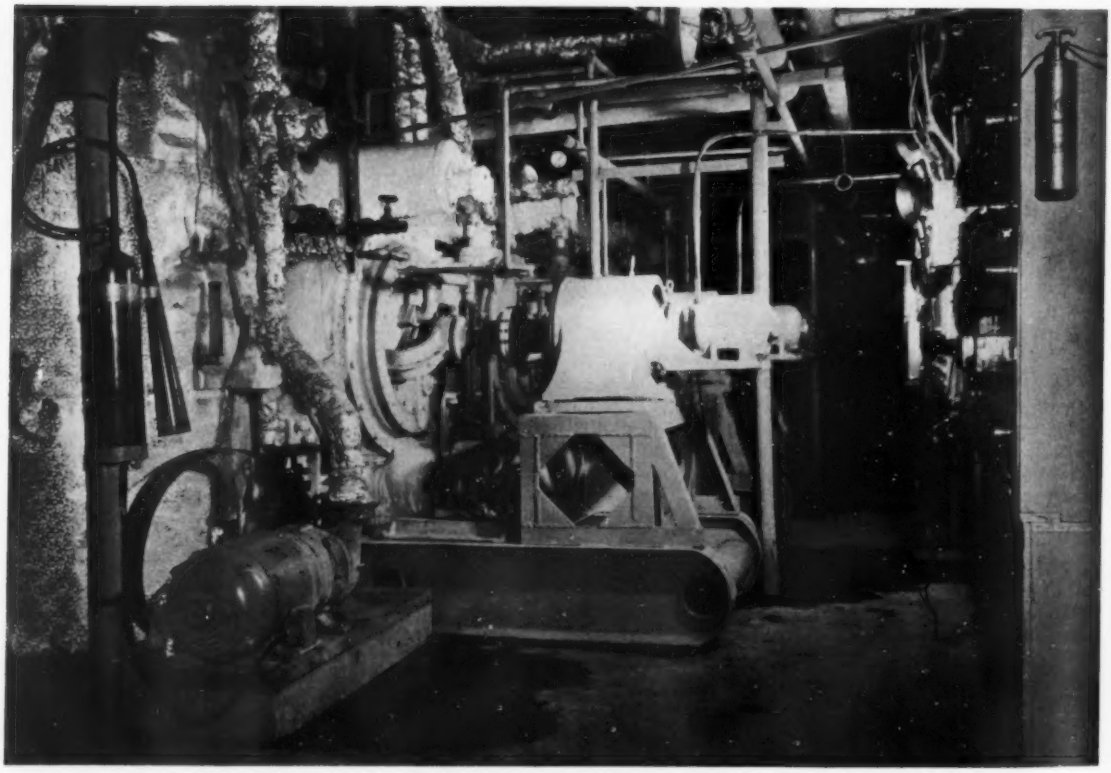

Fig. 3. Four skid-mounted PakIce machines supplying ice crystals to the concrete mixing plant

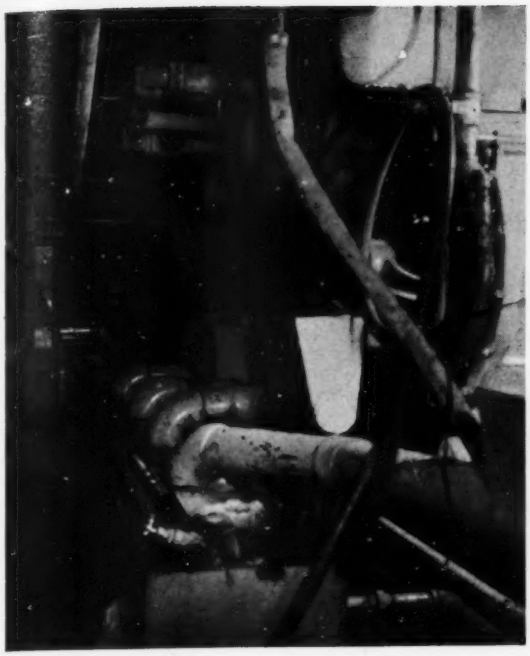

Fig. 4. Ice crystals being discharged into conveyor trough for transport to mixing trough

the next four it is understood that the English Electric and Trading Co. Ltd. has tendered £1,570,000, whereas other offers have ranged from £1,770,000 to £1,890,000, the British concern thus outbidding competitors by a substantial margin. The estimated outlay on this vast project is $206,000,000 or £73,500,000. The generators will be designed to carry an overload of 15 per cent. continuously, and the approximate power head will be 165 ft.

The scheme is designed to be completed in successive stages owing to the fact that there are no practical means of diverting the river. The first stage is well under way and consists of the construction of a cofferdam, Fig. 1, from the north bank of the river to about the centre. The north bank of the river upstream and the bank downstream from the cofferdam are sealed off with blankets of impervious materials. The second stage of the construction is the main barrier dam which is well in hand after 1½ years' work. During this period the concrete batching plant has been erected, the first cofferdam area excavated and two 2,500 ft. long lines erected across the river; the contractors have also constructed the second cofferdam and placed some 220,000 cu. yards of concrete in addition to completing all the excavation work for the power house and intake. The contract covering the construction of the main dam amounts to $27,000,000 or £9,640,000. While the second cofferdam was being constructed alternate blocks in the spillway section were left at a low level as a means of passing large flows, temporary sluices 12 ft. by 14 ft. also being formed in the built-up blocks. The following figures will give some idea of the magnitude of this project:—

Construction Quantities. First 20 units		
Earth excavation	4,400,000	cu. yards
Rock excavation	5,500,000	cu. yards
Concrete	1,700,000	cu. yards
Structural steel	15,000	tons
Reinforcing steel	35,000	tons
Intake Canal and Structure		
Length of intake (27 units)	2,030	ft.
Length of canal	3,000	ft.
Average width of canal	1,000	ft.
Effective head	165	ft.
Depth of canal	30	ft.
Dam Construction		
Length	2,260	ft.
Height above bedrock	220	ft.
Power Installation		
Generators: Rated capacity	64,000	kW
Plant rated capacity (27 units)	1,728,000	kW
Turbines (Francis type) rating	100,000	h.p.

In connection with the concrete batching plant two eight-cylinder ammonia-compressor sets have been installed together with four "PakIce" plants, each having an output of 30 tons per 24 hours. These machines are automatic in operation and produce ice in the form of very small crystals which are ideal for thorough and even mixing. The ice is produced continuously and handled by a conveyor system which passes it to the concrete mixing tower, where measured quantities of crystals are added to the aggregate, replacing part of the water normally used in the mix. During the mixing, setting and hardening of the concrete the heat generated by hydration, which is very rapid at first, is effectively absorbed. This icing system has also been used at other recent dam constructions, e.g. Fort Randall (South Dakota), Allatoona (Georgia), Narrows (Arkansas), with what are considered to be eminently successful results.

Salto de Castro. In connection with the article which appeared in our March issue on this scheme, Boving & Co. Ltd. advise us that the fabricated turbine runner has a diameter of 4,400 mm. and not of 3,400 mm. as stated in the article.

Aluminium Alloys. T.I. Aluminium Limited have issued the first of a series of "Materials and Fabrication" brochures which are designed to give information on the wide range of alloys that are now being produced to meet a great variety of industrial needs.

Jaw and Gyratory Crushers. List No. F122 received from Sir W. G. Armstrong Whitworth (Ironfounders) Ltd. gives the capacity, ratings, power requirements, weight, etc., of their "Kue-Ken" jaw and gyratory crushers.

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high-pressure section of the tunnel the pipe tunnel has been excavated, working through a shaft close to the generating station, and a start has been made on excavating the tailrace from the station.

Consulting Engineers and Architects

The consulting engineers for the civil-engineering works are Sir William Halcrow and Partners, MM.I.C.E., while the consulting work for the electrical and mechanical aspects has been entrusted to Messrs. Kennedy and Donkin. The architects are Messrs. Gratton and McLean.

Impingement Attack in Turbines

The author recounts his experiences with impingement attack in water turbines employed in chemical works and utilising water containing gas in solution. In the light of this experience he propounds an original theory of cavitation corrosion and compares his conclusions with those of Prof. Knapp. This article forms the substance of a paper read before the British Hydromechanics Research Association.

By ERIC CREWDSON, B.Sc. (McGill), A.M.I.C.E.

IN a number of chemical processes scrubber towers are used in which water is introduced at the top of the towers, passes through them absorbing gas, and is finally discharged from the towers. To facilitate the absorption of gas the pressure in the towers is much above atmosphere. The pressure of the water, after discharge from the towers, is at or near atmospheric so as to allow the absorbed gas to be released. The gas-free water is then pumped back to the towers and the process of absorption recommences.

As the pressure in the towers may be several atmospheres and the flow of water appreciable, a large amount of power would be wasted if the water were simply discharged through throttling valves. It is now the general practice to pass the water through turbines and so recover a substantial amount of power which is used to assist in driving the pumps. The power recovered is of the order of 50 per cent. of the total pumping power.

A typical chemical process requiring such scrubbers is the purification of the gases (for the removal of CO_2) in the synthesis of ammonia.

In one works, designated as Works A (see Table I), Pelton wheels have been used supplied with water

TABLE I

Site	Type	h.p.	Inlet Pressure lb/sq.in.ats.	Outlet Pressure lb/sq.in.ats.	Speed r.p.m.
Works A	Pelton	2,200	778	18	600
Works B	Francis	493	150	30	1,480
Works C	Francis	272	185	34	1,450
Works A	Outward flow	1,000	778	145	600

heavily charged with CO_2 and certain other gases at a pressure of about 53 atm. absolute. The gas content is about 10 cu. m. at S.T.P. for every cubic metre of water. The Pelton-wheel casings are provided with water-sealed glands to prevent the escape of gas, and the water and gas are discharged at about 1·2 atm. absolute. In a variation of the process, discharge of the water from the towers takes place in two stages. The first stage lets the gas-charged water down to about 10 atm. absolute. A proportion of the CO_2 and nearly all the other gas is released at this stage. The remaining absorbed gas is nearly pure CO_2, and a second-stage let-down process reduces the water pressure from 10 atm. to approximately atmospheric.

At a second plant, Works B, water enters the turbines at 10 atm., and contains about 3 cu. m. of gas at S.T.P. per cubic metre of water. It is discharged from the turbine at about 2 atm.

At a third plant, Works C, the water enters the turbines at 12·5 atm. and contains mainly CO_2 in solution with some H_2S. It leaves the turbine at about 2·3 atm.

The turbines at Works B and C have suffered from impingement attack and it is this form of attack that the author proposes to describe in some detail. The Pelton wheels at Plant A were installed in the years 1926 to 1928, and at first suffered severely from attack of a different type. A change from cast steel to stainless steel in the nozzles and buckets completely cured this type of attack.

The turbines at Works B and C were medium-specific-speed turbines of normal Francis design with spiral casings and outside guide-vane-operating mechanism.

For the two-stage let-down process mentioned earlier, only the first-stage turbine has so far been installed. Its design is unorthodox in that it is of the radial outward flow type.

Turbine at Works C

When this plant was first erected shortly before the second world war, a power-recovery Francis turbine made by Voith of Germany was installed. The runner and guide vanes were made of bronze. It was never

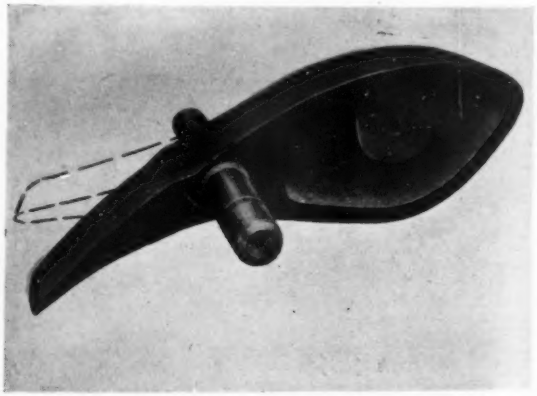


Fig. 1. Bronze guide vane from Voith turbine showing severe distortion (Original profile indicated by dotted line)

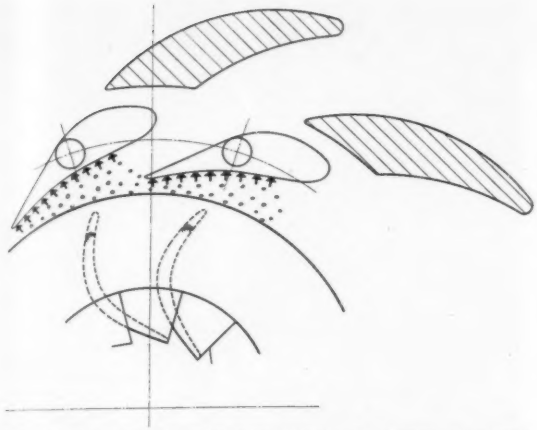


Fig. 2. Section of turbine at Works C. Areas of attack indicated by small rings and arrows

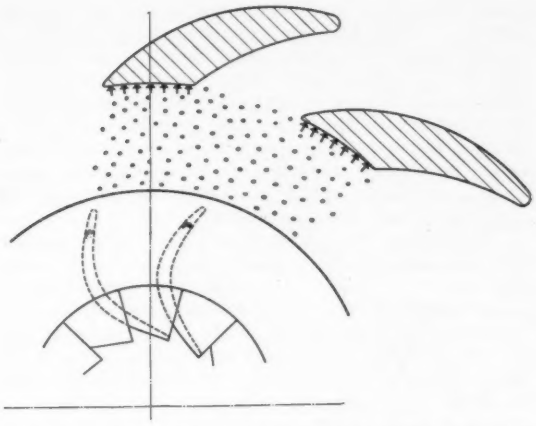


Fig. 3. Section of turbine at Works C with movable guide vanes removed. Areas of attack indicated by small rings and arrows

run at full capacity because the operating staff found the noise and vibration too serious, and it was run normally about half capacity or less. In 1943 Gilbert Gilkes and Gordon Limited were asked to supply spare parts. The condition of the Voith turbine at that time can be judged from the photograph of a guide vane shown in Fig. 1; the tip of the guide vane has been hammered over a matter of 2 in. or so.

Gilkes subsequently supplied a replacement for this turbine and used phosphor bronze for the guide vanes and guide-vane-chamber liners. After a few weeks working the impingement attack on the guide vanes was so serious, and the consequent distortion of the guide vanes so considerable, that they could not be moved. Replacements were made and some alterations to the design of the runner were adopted. The new runner, guide vanes and guide-vane-chamber liners were made in stainless steel. With these alterations, the turbine has been in satisfactory operation for some two years.

In the Gilkes bronze-fitted turbine the attack was concentrated as shown in Fig. 2. At first it was thought that a greater clearance between the runner-vane entrance edges and the exit from the guide vanes might improve matters, and the first alteration made was to turn off the edges of the runner vanes and redress them by hand at a smaller diameter. The guide vanes were also hand dressed so as to make them operable once more. The result was disappointing. More rapid and severe attack took place than before.

The second alteration was to take out the guide vanes altogether and rely on the spiral form of the casing to direct the water on to the runner. The result was astonishing. Gilkes' engineer who started up the turbine after these alterations was so disturbed by the really appalling noise made by the turbine that he had it shut down after a few minutes run. The damage that had occurred in those few minutes was remarkable. The area attacked is indicated in Fig. 3. It will be noted that the damage reached back to the inner faces of the fixed stay vanes in the casing.

The alterations that were successful were to increase the effective diameter of the runner so as to bring the vane entrance edges nearer to the guide-vane exit edges, increase the number of the runner vanes, and make the runner and guide vanes and guide-vane-chamber liners of 12 to 14 per cent. chromium stainless steel. It is now believed that stainless steel containing 18 per cent. chromium 8 per cent. nickel would have been a more suitable material owing to its exceptional work hardening properties.

Turbine at Works B

This turbine was started up in July 1951 and run successfully until April 1952, when it had to be shut down due to a failure of the thrust bearing. On examination it was found that substantial impinge-

Fig. 4. Turbine runner at Works B

ment attack had occurred and also that one of the clearance rings which had been shrunk on the outside of the runner skirt had come loose and worked its way into the space between the runner vanes and the guide vanes. Figs. 4, 5 and 6 are photographs of the runner, a guide vane and one guide-vane-chamber, and show the damage that had occurred. The loose clearance ring did considerable damage to the runner vanes and finally broke up. Only one piece of the ring was found, about 2 in. long.

The runner, the guide vanes, the clearance rings and the guide chamber facings were made of stainless steel containing 12 to 14 per cent. chromium.

The area which had suffered impingement attack is clear from the photographs. The turbine had run about 7,400 hours with the guide vanes set to pass about half to two-thirds of the turbine's rated discharge.

Outward-Flow Turbine at Works A

When the design of this turbine was being discussed the author's experience with the turbine at Works C led him to hesitate to put forward a normal inward-flow Francis turbine for the exceptionally severe conditions. The inlet head was about four times that of the turbine at Works C, and was higher than had ever before been applied to a Francis turbine. A Pelton wheel was ruled out of court by the enormous windage loss which would have occurred with the required discharge pressure (10 atm.). One of the original Pelton wheels had in fact been fitted by the users with a strengthened casing to stand the discharge pressure of 10 atm. When it was started up the full supply of water was turned on but the Pelton wheel did not quite run up to speed and about 150 kW had to be put into the alternator to bring it to synchronous speed. The density of CO_2 is substantially greater than that of air, and is increased ten times at the actual discharge pressure.

The design adopted was an outward-flow Girard turbine with full injection. A view of the turbine is shown in Fig. 7. The turbine was designed to use 1,500 cu. m. per hour of water and to develop about 1,000 h.p. Owing to the difficulty of getting stainless steel for the runner it was made of mild steel.

Fig. 6. Turbine guide vane chamber at Works B showing area of impingement attack

Although the turbine ran satisfactorily, its efficiency was much lower than had been anticipated. The author made a number of suggestions for improving the efficiency but no improvement was obtained. It has been decided to revert to the original design and make the runner in stainless steel containing 12 to 14 per cent. chromium.

The turbine has run for 12,000 hours and though the mild-steel runner shows quite marked deterioration this is not the result of impingement attack but of the type of corrosion typical of the action of CO_2 on mild steel. Some trouble has been experienced with the thrust bearing.

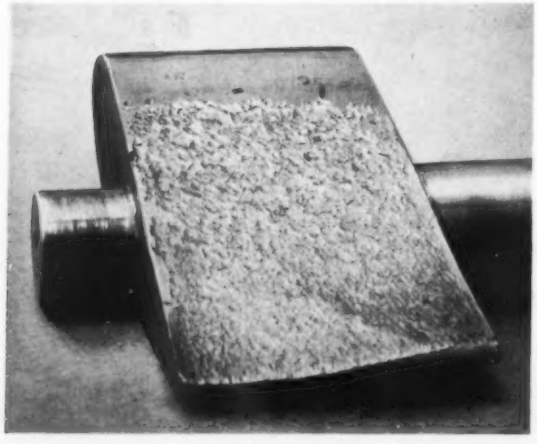


Fig. 5. Turbine guide vane at Works B showing area of impingement attack

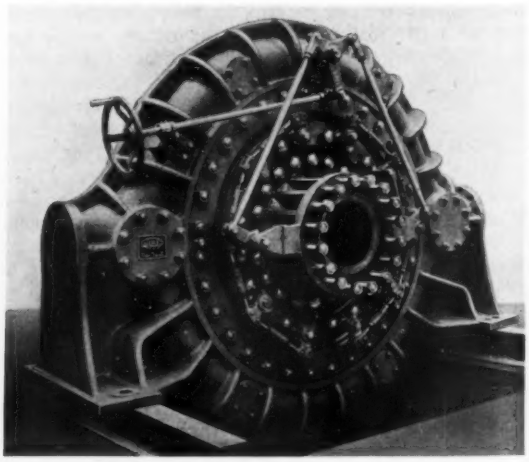


Fig. 7. Outward-flow turbine installed at Works A

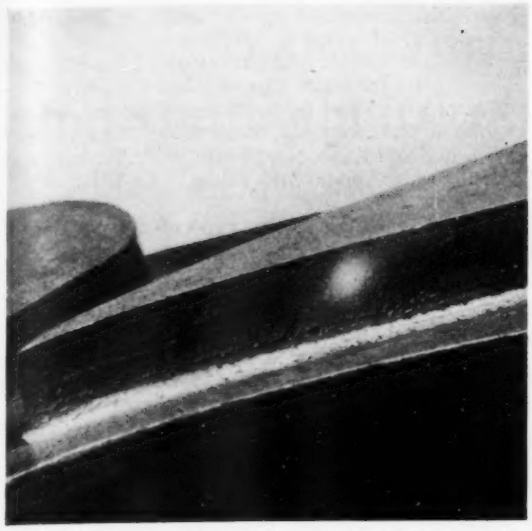


Fig. 8. Air-expansion-turbine guide vane illustrating impingement attack

Under the rated working conditions, the best efficiency so far obtained has been about 55 per cent. If the back pressure is reduced, the efficiency rises substantially. It was anticipated when the turbine was designed that an efficiency of 75 per cent. would be obtained.

Causes of Impingement Attack

A tentative suggestion is that impingement attack is due to a condition of instability in the interspace between the guide vanes and runner vanes, combined with action of gas bubbles as studied by Lord Rayleigh in his Scientific Paper No. 423, 1917. The pressure round the periphery of the runner vanes varies because it is clearly higher at the working face than at the back of each runner vane; otherwise no power would be produced. The mixture of water and gas in the interspace is highly elastic; and the variation of pressure as each runner vane passes across a guide-vane discharge stream could start an important oscillation in the interspace. The author is by no means sure that the observed damage is done solely by the water, but thinks that the spearhead of an attack may be a bubble of highly compressed and therefore very hot gas (see Note B).

It is interesting that somewhat similar impingement attack occurs in inward-flow air expansion turbines. The scale of attack, that is, the size of the resulting "pits" in the metal, is enormously less, but the general character of the attack is similar. This is illustrated in Fig. 8, which shows the inner surface of the guide vane of an inward-flow expansion turbine. The turbine had run for about 150 hours at about 48,000 r.p.m. No such damage occurs in an outward-flow expansion turbine.

By following the argument indicated by Lord Rayleigh (Scientific Papers, Vol. VI, No. 423, 1917) and developing it on the assumption that compression of a CO_2 bubble is approximately adiabatic ($\gamma = 1{\cdot}2$) and not isothermal it appears that in order to compress a bubble of gas surrounded by water to one three-hundredth of its original volume the pressure in the field of water must be about 10·65 times the initial pressure of the bubble. If a hemispherical bubble of CO_2 gas, initially at a temperature of 20°C., and a pressure of 6 atm., is adiabatically compressed to one three-hundredth of its initial volume, its temperature will rise to 757°C., its pressure to 40·3 tons per sq. in., and its density to 207 lb. per cu. ft. The ultimate stress of 13 per cent. chrome steel at 20°C. is about 39 tons per sq. in., and at 600°C. about 19·8 tons per sq. in. The skin of the metal in contact with the hot gas would begin to flow under the pressure of the gas, and the work done on the metal would still further increase its temperature.

In the turbine at Works B the pressure of the water and gas in the space between the exit from the guide vanes and the entrance to the runner vanes would be of the order of 6 atm., if there were no oscillations of pressure here. In order that sufficient pressure should be available in this space to compress a gas bubble to one three-hundredth of its initial volume there must be such oscillations of pressure in the space that at some period of the oscillation the pressure rises at least to $10{\cdot}65 \times 6{\cdot}0 = 64$ atm.

By making certain reasonable assumptions as to the proportion of gas and water in the space it is possible to calculate that a fluctuation of pressure of 15 to 20 lb. per sq. in. — corresponding to the probable difference of pressure between the working and non-working faces of the runner vanes in the turbine at Works B—might set up a condition approaching resonance in the space. It seems then extremely likely that the pressure of 64 atm. could easily be exceeded, for the short space of time required to compress the bubble. Suppose the final radius of the bubble is 0·05 in., its initial radius would be 0·335 in. The time taken for the compression would be of the order of 0·0001 sec.

The speed with which the water carrying the bubble is travelling past the guide vane is about 75 ft. per sec. The bubble during its compression would travel about 0·04 in. A perfectly spherical bubble would therefore tend to make an elliptical depression in the metal in which the major axis would exceed the minor axis by this amount.

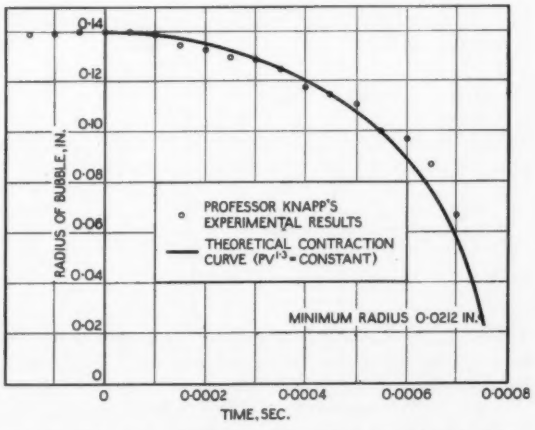


Fig. 9. History of contraction of cavitation bubble. Note: The time when the bubble attained its maximum dimensions has been taken 0·00005 seconds earlier than in Fig. 15 of Professor Knapp's lecture

Comparison with Prof. Knapp's Results

If vapour bubbles produced under cavitation conditions are compressed adiabatically, they do not collapse as is sometimes supposed. They are momentarily compressed to a minimum finite size and in that condition contain highly superheated steam at a substantial pressure.

Prof. R. T. Knapp, in his James Clayton lecture delivered in April 1952 at the Institution of Mechanical Engineers, studied the life history of a spherical cavitation bubble having a maximum radius of 0·14 in. The bubble was formed in water at a temperature corresponding to a vapour pressure of 0·4 lb. per sq. in. (abs.) (73°F.). The water pressure in the field of water where the bubble was contracting was approximately 3 lb. per sq. in. (abs.). Owing to the rapid rate at which the bubble was formed it is probable that the pressure in the bubble before it started to contract was substantially less than 0·4 lb. per sq. in. (abs.).

If we assume that the actual vapour pressure was 0·2 lb. per sq. in. (abs.) (corresponding to a temperature of 54°F.) and that the bubble was compressed according to the law $PV^{1\cdot3}$=constant, its minimum volume would be one two-hundred-and-eighty-seventh of its maximum volume. The bubble would then have a radius of 0·0212 in. and would contain vapour at a pressure of 283 lb. per sq. in. (abs.) and at a temperature of 2043°F.

In Fig. 9 the calculated compression curve of the bubble is shown plotted together with Prof. Knapp's observed points and follows these points reasonably closely.

If a compressed bubble containing such highly superheated steam came in contact with a surface of cast iron, say, it is probable that it would attack the carbon contained in the iron and cause damage of the type which cast iron does suffer under cavitation conditions.

Appendix

The formulae used to calculate the times of compression of bubbles were as follows:—

(i) $$U^2 = \frac{2P}{3\rho}\left(\frac{R_o^3}{R^3} - 1\right)$$

This is Lord Rayleigh's equation (4) and applies to an empty bubble.

(ii) $$\tau = 0{\cdot}9147\ R_o\sqrt{\frac{\rho}{P}}$$

This is Lord Rayleigh's equation (6) and gives the time of complete collapse of an empty bubble.

(iii) $$U^2 = \frac{2P}{3\rho}\left(\frac{R_o^3}{R^3} - 1\right) - \frac{2Q}{3\rho}\frac{R_o^3}{R^3}\left[\frac{\left(\frac{R_o}{R}\right)^{3\gamma-3} - 1}{\gamma - 1}\right]$$

This is Lord Rayleigh's equation (7) modified by Dr. B. Heys to allow for adiabatic instead of isothermal compression of a gas bubble.

(iv) The meanings of the symbols are:—

U = velocity of the boundary of the bubble.
R_o = initial value of the radius of the bubble.
R = radius of the bubble at time t.
P = pressure in the field of water compressing the bubble.
Q = initial pressure of gas or vapour in the bubble.
ρ = density of water.
γ = ratio of specific heats, taken as 1·2 for CO_2, and 1·3 for water vapour.

The pressures and temperatures of the gas and the vapour bubbles were calculated using "Gas Tables" by Keenan and Kaye, New York, 1948. Table 16 was used for water vapour and Table 17 for CO_2.

For a given ratio $\frac{P}{Q}$, the ratio of compression of a bubble $\left(\frac{R}{R_o}\right)^3$ was calculated by Lord Rayleigh for isothermal compression of a perfect gas contained in the bubble surrounded by water. Table II gives Lord Rayleigh's figures and compares them with the ratios which would be obtained if gases were compressed adiabatically, which followed the relations $PV^{1\cdot4}$=constant, and $PV^{1\cdot3}$=constant.

TABLE II

$\left(\frac{R}{R_o}\right)^3$ ratio of volumes	$\frac{P}{Q}$ ratio of pressures		
	Isothermal (Rayleigh)	Adiabatic $\gamma=1{\cdot}4$	Adiabatic $\gamma=1{\cdot}3$
1/1000	6·91	37·4	23·1
1/300	5·65	22·1	15·2
1/100	4·65	13·4	10·0
1/10	2·56	4·2	3·68
1/4	1·85	2·47	2·39
1/2	1·38	1·60	1·54

From page 130

adits and short shafts, and the estimates both of time and of cost are based on the assumption that the mines in the copper belt will co-operate with the supply of skilled labour. Taking the longest drive as 2½ miles, it is computed that the tunnel would take 39 months to construct. The dam should not take more than 30 months.

The ruling factor for the time schedule of the whole scheme is deemed to be the delivery of the generating sets. It is assumed that the first generating set should be delivered ex works in three years from the date of the order and would require a further year for transport and erection, further sets following on at three-monthly intervals. Allowing six months for design and letting contracts and a further six months for contingencies the first unit should be in operation in 5 years from the decision to proceed and the fourth unit in 5¾ years.

If desired the scheme could be constructed in two stages, the upper station being built first and the lower station deferred until later, but on the assumption that the entire scheme proceeds simultaneously it should be in full operation in 6¼ years.

The estimated capital costs are £20.924.000 for the initial scheme (upper station only) and £27,597.000 for the full scheme, of which £9,457.000 is for transmission. The costs per kWh received on the low-voltage side of the receiving stations are computed to be 0·400d. at average output for the initial scheme and 0·258d. for the full scheme.

NOTE. The drawings accompanying this summary have been reproduced from the report, and for the views of Kafue Gorge we are indebted to Mr. Geoffrey Kennedy.

Water Turbine Governors and the Stability of Hydro-Electric Plant

In this series of articles, the water-turbine governor is considered in relation to control of the electrical transmission network, as well as to regulation of the water supply system, including the surge tank. The principles underlying the design and operation of water-turbine governors are reviewed and a typical oil-pressure governor is described in some detail, along with its pressure oil supply. A short general account of the double regulation system for water turbines is then given, and is rounded off by a discussion of the stability of water-turbine governors.

By N. G. DENNIS, M.A., D.I.C., A.M.I.Mech.E., A.M.I.E.E.

PART THREE

WHEN two separate devices for modifying the flow of water to the turbine are operated independently by the governor, the arrangement is known as "double regulation." The usual forms of double regulation are outlined below.

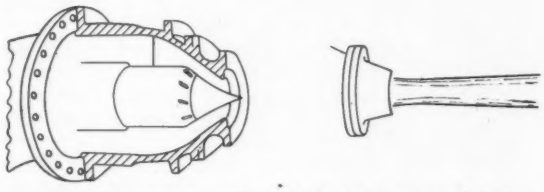
Guide Vanes and Runner Blades of Kaplan Turbines. In order to obtain the best efficiency for any load on the turbine, the guide vanes and runner blades must be adjusted to their correct relative positions. Usually the guide vanes are operated in the normal manner, while the angle of the runner blades is determined by means of a cam positioned according to the guide-vane setting.

In most cases, the control of the runner blades is affected through a pilot relay followed by a displacement transmission system (Fig. 7b). Since the runner blades and their operating servomotor rotate together, a pressure oil seal has to be provided somewhere on the shaft. Usually this is at the shaft head, but in recent years attention has been directed to the turbine guide bearing, which with its small clearance forms a natural seal for the pressure oil supply to the rotating shaft.

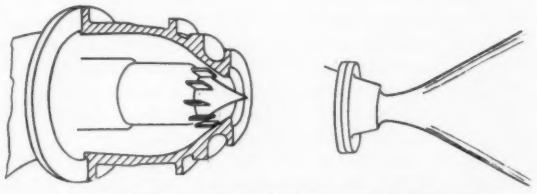
Guide Vanes and Relief Valve. The relief valve is introduced to limit the rise in water pressure that occurs in a pipeline when the turbine undergoes rapid closure. The guide vanes are controlled by the governor in the usual manner, and the relief valve is operated in unison with and proportional to the guide-vane movement. There are many different designs, but all are believed to apply the principle of the temporary-transmission mechanism shown in Fig. 21. On a sudden drop in load, the relief valve is opened to the desired extent and then slowly closes.

Pressure water from the pipeline is used in many cases to operate the relief valve. The temporary-return-motion mechanism differs from that within the governor, because displacement from the position of rest is in one direction only. When the relief valve is arranged with axis vertical, the springs shown in Fig. 21 can be omitted, and the restoring force can be provided by gravity plus water pressure acting on either the piston or the cylinder.

Spear and Diffuser Operation for Pelton Turbines. Double-regulation systems for Pelton turbines are similar to reaction turbines with relief valves in-so-far as excessive pressures rises after major load rejections are prevented by temporary diversion of flow. One such device for Pelton turbines is the diffuser. Under steady-state conditions, the ends of the diffuser blades (Fig. 25a) are retracted into the spear and the two form a continuous smooth surface. When the turbine has to reject load suddenly, the diffuser shoots quickly forward into the water stream within the nozzle (Fig. 25b) and diverts it from the buckets of the Pelton runner. The spear follows the diffuser slowly and reduces the flow of water at the rate prescribed by the hydrodynamic and mechanical conditions. The com-



a Normal position under steady load with solid jet



b Diffuser in acting position and hollow jet

Fig. 25. Spear, diffusing blades, and jet

bination of spear and diffuser then settles down to a new steady position. Further information is given by Seewer (1936). The transient diversion effect of the diffuser is the result of the inclination of the diffuser blades. These cause the solid jet to break up to the desired extent into a hollow-vortex cone.

The governor acts directly on the diffuser. The spear follows the movement of the diffuser as determined by a mechanism which is a special development of the pilot nozzle shown in Fig. 17a. This enables the spear to follow the diffuser instantaneously during small movements, thus ensuring good stability. However, for large movements of the diffuser, the mechanism quickly reaches saturation and the spear then moves only at such speed as permitted by the pipeline conditions.

Spear and Deflector Operation of a Pelton Turbine. The deflector is an alternative device to the diffuser, and is shown in Fig. 26. As with the diffuser arrangement, the spear controls the size of jet issuing from

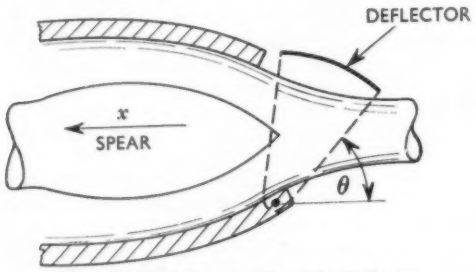


Fig. 26. Pelton nozzle with deflector

the nozzle and hence the steady-state power.

The deflector must be arranged always to be just clear of the jet, whatever its size, under steady-state conditions. When a rapid drop in the electrical load occurs, the deflector is thrust into the jet and diverts a certain amount of it from the runner buckets. As the spear slowly reaches its new steady-state position, so the deflector gradually moves out of the jet.

Pressure-Oil Supply to Governor

The oil is supplied to the governor at a pressure of 200-300 lb. per sq. in., or more if required. The amount of pressure oil used by the governor depends on whether it is operating under a steady load, or whether it is controlling changes of load. When the load is steady, only the leakages through the operating clearances of the various mechanisms will be supplied, but during large load changes the servomotors absorb a much greater flow of oil.

With small turbines, usually a single oil pump is kept running continuously, and, when not supplying oil to the governor, discharges back into the sump through a spring-loaded valve. An alternative is a two-pump arrangement in which the small pump supplies the continuous basic leakage and the big pump idles except when the load change and hence the distributing-valve movement exceeds a certain value, at which an oil relay diverts the supply to the governor. No accumulator is used in either case.

Such arrangements are not economical for large turbines, where a comparatively small pump works for relatively long periods to store oil under pressure in an accumulator. With such turbines, a single stroke of the main servomotor may release more than 300,000 ft. lb. of energy in a few seconds, *i.e.*, the servomotors may operate at more than 300 h.p.

Within the pressure receiver, the ratios of the volume of air to the volumes of oil in the receiver and main servomotor have to be considered carefully, since these determine the drop in pressure during a full stroke of the servomotor and the number of successive strokes which can be made. Under steady conditions the required pressure and the appropriate level of oil have to be maintained in the receiver by pumping in oil and occasional topping up with air. Usually the setting of an idler valve determines the pressure of the oil supplied to the receiver. If any appreciable amount of air has dissolved in the oil or has mechanically leaked away, the oil level becomes too high and air must be injected into the receiver. This supply of air can be arranged in the following ways:—

(1) from a separate air compressor;

(2) by admitting air into the oil stream on the suction side of the pump;

(3) by utilising the pressure oil as the piston of a reciprocating pump. This oil surface reciprocates up and down in a separate vertical chamber adjacent to the pressure receiver. At the end of each upward vertical stroke a charge of air followed by a stream of oil can be delivered into the receiver by way of a non-return valve. This chamber is in the direct line of supply from the pump to the pressure receiver, and the system makes use of the intermittent nature of the supply as determined by the idler valve described below. Further details are given by Fabritz (1940).

Idler Valve

This is sometimes known as a 'changeover' or 'bypass' valve. By unloading the pressure on the pump while not required to deliver to the accumulator, it reduces the energy consumption and wear of the governor oil pump and also avoids excessive heating of the oil.

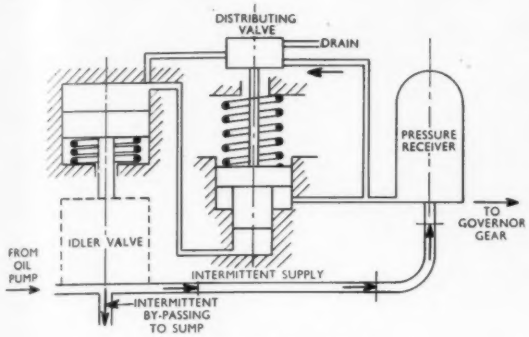
The governor oil pump runs continually and discharges directly into the pressure receiver, except when the flow is diverted by the idler valve to the sump. The governor makes continual though varying demand on the pressure receiver which causes a gradual decrease in the oil pressure. Within the design limits, the idler valve can be adjusted to operate at any desired pressures, *e.g.*, 270 to 300 lb. per sq. in. When the pressure has fallen to 270 lb. per sq. in. the idler valve diverts the discharge to the receiver; then, as the pressure rises to 300 lb. per sq. in. it connects once again to the sump.

In addition to the changeover action described above, this valve also acts as a safety valve, although for greater security it is usual to provide separate safety valves also.

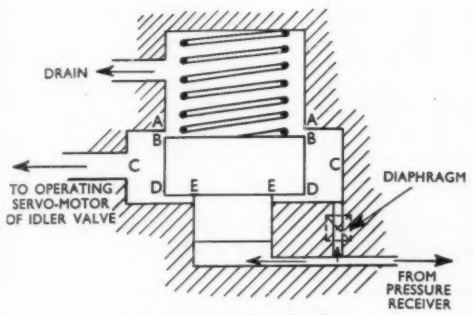
Fig. 27a shows one type of device for obtaining the changeover action. This employs a pressure feed-back from the piston of the idler valve. A brief examination will show that the ratio between the limiting pressures (*e.g.*, 300 lb. per sq. in. to 270 lb. per sq. in.) is determined by the ratio of the two areas on the small piston controlling the movement of the main piston, and the magnitude of the pressures is determined by the strength of the spring.

A neat method which utilises the simple piston-cum-spring arrangement is shown in Fig. 27b and is

given by Ribaux (1947). In essentials, the edges *AA* and *BB* control the escape of oil from chamber *C*, and hence determines whether or not oil pressure is applied to the annular area *DE*. This device is similar to the arrangement shown in Fig. 27a except that the physical arrangement of the distributing valve and pilot servomotor is simpler.



a Separate feed-back



b Integral feed-back

Fig. 27. Idler valve control system

A second way to obtain the above result is shown in principle in Fig. 31. The central spindle is operated by a spring-loaded piston. It is so arranged that its position depends only on the oil pressure in the accumulator and it is, in effect, a pressure gauge. This pressure-gauge spindle is surrounded by the separately moving main piston which operates the idler valve. It is not proposed to enter into further details here, but oil passages and a double-face seating valve can be arranged between the pressure-gauge spindle and the main piston to control the latter in the desired way. When the accumulator reaches the desired top limit of pressure, the pressure-gauge spindle will be located in its extreme left-hand position in which it causes the oil pressure in chamber *B* to build up suddenly while the pressure in chamber *A* diminishes. The piston then moves rapidly through its full stroke to its extreme left-hand position. A similar action takes place when the lowest desired pressure in the receiver is reached. Further information is given by Fabritz (1940) and Ribaux (1947).

Special Functions of a Governor

Water Level Control. Arrangements are sometimes made for control of the headwater or the tailwater level. The state of the water level is then relayed to the governor as shown in Fig. 4a. The transmission can consist of a float with mechanical linkage, a float with geared synchronous electric transmission, or various forms of pneumatic arrangement.

The water level in a surge tank or free-level canal can be arranged to influence the governor through a temporary-transmission mechanism as a transient feed-back. Such an arrangement can stabilise an otherwise unstable surge tank, but at the price of slow oscillations of the turbine power. This can be done also by a pressure-sensitive device at the turbine.

Frequency Control. Three devices are available to check or actually control the frequency. These provide the load despatcher with the value of frequency, the rate of change of frequency, and the difference between frequency time and accurate chronological time. Any of these elements can influence the governors of a number of turbines, and can provide a slow secondary control of turbine speed and hence frequency. The control is usually manual but a comparatively recent development is the adoption of automatic control. This often acts by way of the change-of-speed device of the turbine governor.

Rapid Frequency Control. For special frequency-controlling stations, extremely rapid adjustment of load is desirable. Water turbines are especially suitable for handling large sudden load changes, since, unlike other turbines, the working fluid is always on tap and can be cut off instantly without thermal difficulty or waste. If the rapidity of action of the change-of-speed device is considered insufficient a special mechanism can be introduced (Stein 1951) in the case where there is a final displacement-transmission mechanism (Fig. 7b) in the control of the guide vanes. This takes the form of an additive device placed immediately before this mechanism in the control sequence, and this enables a rapid frequency control movement to be superimposed on that emanating from the rest of the governor. The speed of the latter movement is directly limited by stability, whereas the speed of the rapid frequency-control movement is limited chiefly by the maximum pressure variations permissible in the intake and discharge passages of the turbine. It should be noted that a water turbine cannot take on load faster than a certain rate which is determined by the prevailing head available to accelerate the water in the pipeline and turbine.

Special load control between units of the same station. Although tie-line-bias control is recognised nowadays as the best method of controlling the power distribution and frequency on very large power systems, there are still instances where a selected power station is designed for sensitive isochronous governing. This plant then meets all the sudden changes of load

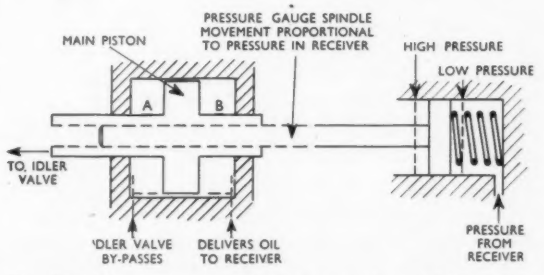
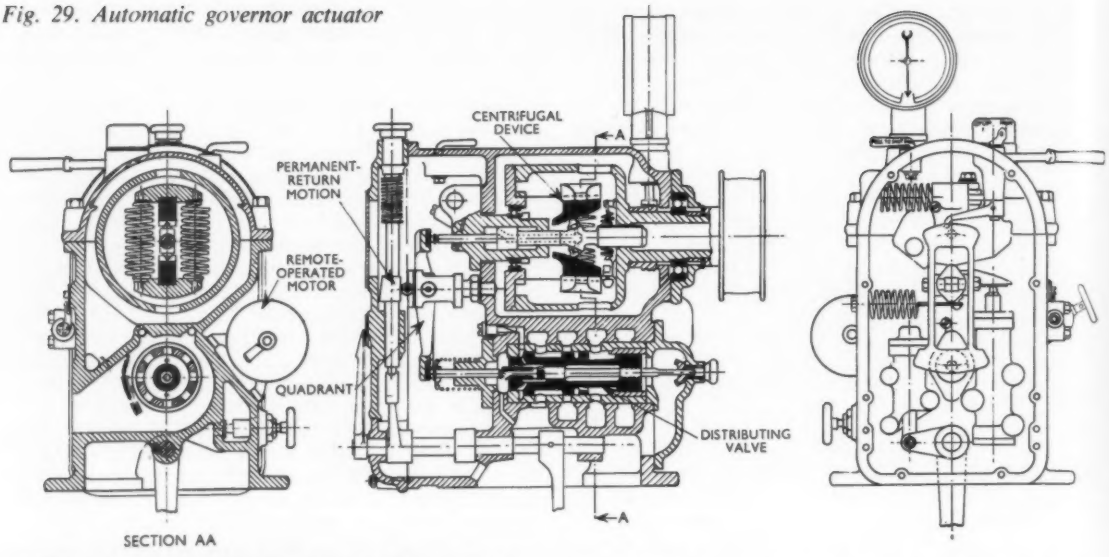


Fig. 28. Alternative method of operation of idler valve

Fig. 29. Automatic governor actuator



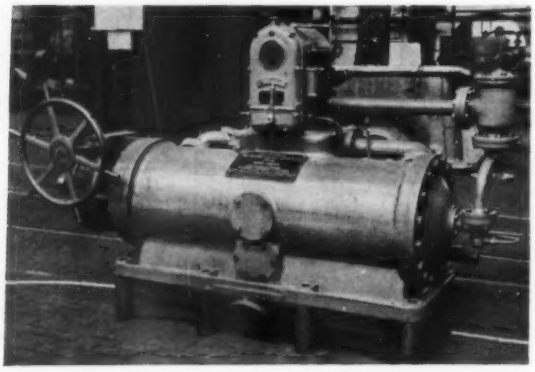


Fig. 30. Governor actuator and servomotor

on the network. The stable parallel operation of the generating units within this power station can be effected in several ways:

(1) with a direct isochronous control of only one unit. The movement of the turbine guide vanes is then relayed to the governors of the other turbines and thus determines their guide-vane opening.

(2) with each unit under control of its own isochronous governor. The guide-vane opening of one turbine acts on the other turbine governors in such a way as to ensure stable assignation of load.

(3) with a single master isochronous regulator, which assigns directly to each unit the desired proportion of a load change.

Methods (2) and (3) are superior because they cater more rapidly for large load changes. All methods permit of the total station load being apportioned as desired between the various turbines.

Tie-Line Load Control. Tie-line load control may be desirable for two reasons. Firstly, operation of the network may require tie-line-bias control to vary the tie-line load according to the frequency. Secondly, the tie-line may connect two differently owned power networks for which the power exchange may have been fixed by a contract agreement.

Normally, a generating set will have a speed-load droop which is produced by the rigid return-motion from the main servomotor movement. For tie-line control this feed-back is removed, and is replaced by electrical measurement and transmission of the tie-line load. The unit so arranged then bears responsibility for this load with any required tie-line-bias characteristic (frequency power regulation) relative to the interconnected networks.

ACKNOWLEDGMENT. The illustrations accompanying this instalment are reproduced from the author's paper " Water Turbine Governors " presented to the Institution of Mechanical Engineers on November 7, 1952. Much of the information contained in this series of articles is also repeated from that paper.

(To be continued)

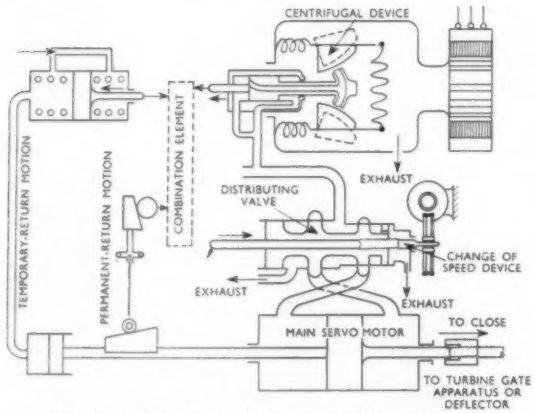


Fig. 31. Diagram of water-turbine governor

Messrs. Kennedy & Donkin, Consulting Engineers, London, announce that Mr. W. D. Wheeler, A.M.I.E.E., M(SA).I.E.E., has joined them as their chief representative in Southern Africa. He will be in charge of their office in Johannesburg, at 22 Amershoff Street, Braamfontein.

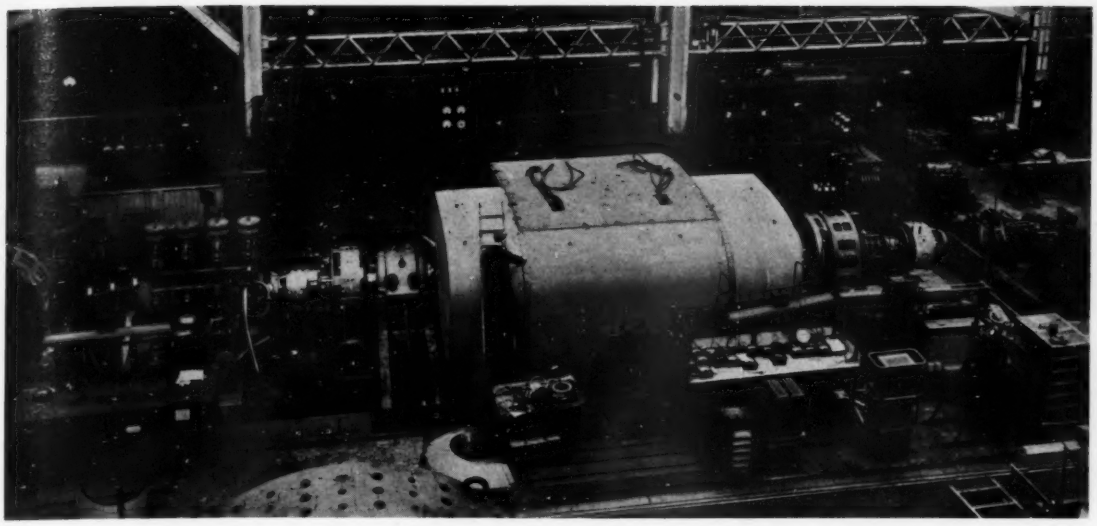


Fig. 1. The 40 MVA synchronous condenser on the testbed

A 40 MVA Synchronous Condenser

The largest synchronous condenser yet built in Great Britain has been constructed by Metropolitan-Vickers Electrical Co. Ltd. for the State Electricity Commission of Victoria, Australia.

THE synchronous condenser is becoming an increasingly important means of improving the power factor of large networks. It possesses an inherent advantage over the static condenser in that it cannot only correct the lagging power factor of a loaded system but can be under-excited to correct the leading power factor of a lightly loaded transmission line.

This type of machine is of particular value where hydro-electric schemes are concerned, because the long transmission lines characteristic of such schemes render power-factor correction a vital consideration. For instance, in the recently published report on the Kafue Gorge scheme, reviewed elsewhere in this issue, two 40 MVA synchronous condensers are recommended to be installed at the receiving substations in Northern and Southern Rhodesia respectively. Again, Metropolitan-Vickers Electrical Co. Ltd. has supplied, or has on order, no fewer than 23 machines of 20 MVA capacity for the late Victoria Falls and Transvaal Power Company and its successor, the Electricity Supply Commission of South Africa, in addition to some of 6 MVA, and has built others, ranging from 3 to 30 MVA, for European countries, India and New Zealand.

In the network operated by the State Electricity Commission of Victoria, Australia, the problem of power-factor correction is important because of the large proportion of power generated in comparatively remote stations operating on brown coal or water, and will become increasingly so when supplies from the first section of the Kiewa scheme and from Snowy Mountains become available. To meet this situation a 40 MVA synchronous condenser is to be installed at the Malvern terminal near Melbourne, and we recently had the opportunity of inspecting the machine in operation on the testbed at the Metropolitan-Vickers Trafford Park works prior to dispatch (see Fig. 1).

This machine is the largest synchronous condenser yet built in Great Britain, and although it generally follows the standard design favoured by Metropolitan-Vickers for machines of this type it incorporates a number of interesting and unusual features. In the first place the solid-pole rotor construction, which in itself is a standard feature, has enabled an unusually high speed to be adopted — 1,000 r.p.m. — without incurring any difficulty with centrifugal stresses or critical speeds, so that a smaller frame size can be used for the required capacity, with a corresponding reduction in capital cost. Incidentally, this construction permits the use of a long small-diameter rotor, with the result that the windage loss, which varies with the fifth power of the diameter, can be kept to a minimum.

Secondly, the stator winding operates at the unusually high voltage of 22 kV, which is that of the distribution system to which the machine is connected.

One of the most interesting features of the machine is the means by which building costs have been

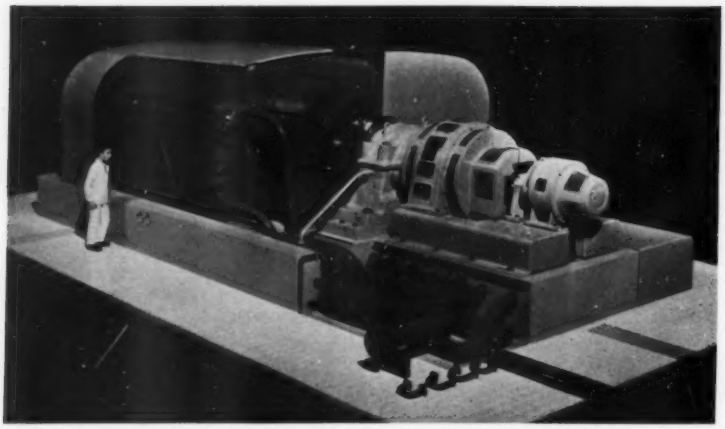


Fig. 2. Model showing starting motor, air cooler, and oil coolers. One oil cooler has been drawn forward for inspection

minimised. By adopting a special design of closed-circuit ventilation system with coolers placed at the sides of the stator, it has been possible to dispense with a basement. The machine is carried on a concrete plinth, 30 in. high, and the only excavation required is for the oil tank. Furthermore, the design has been ingeniously disposed so that erection and dismantling can be carried out entirely by means of four 20-ton hydraulic jacks and a 3-ton mobile crane, although the heaviest lift—the rotor—is 61 tons. Thus the cost of a crane of this capacity is avoided, together with that of a building strong enough to support it.

The condenser is rated at 40 MVA at zero leading power factor (over-excited) and 25 MVA at zero lagging power factor (under-excited), total losses being less than 2 per cent. of the kVA rating. It will be automatically controlled by voltage regulator to maintain the system voltage. Excitation is provided by a main exciter rated at 200 V 575 A (115 kW) continuously, with a peak output of 370 V 1,050 A for super-excitation. A differential field winding provides a voltage variation of 10 : 1 to cover the range of output of the condenser, and this winding is supplied from an auxiliary exciter rated at 230 V 28 A (6·5 kW) continuously with a peak output of 36 A at substantially constant voltage. Both exciters are overhung at the slipring end of the main shaft.

The machine is also designed for use as a generator for line charging, and for this reason it is direct coupled to a synchronous induction motor which acts both as a starting motor and as the driving motor when the machine is line charging. This motor is rated at 1,160 h.p.; it is supplied from the substation 2·2 kV busbars, and carries its own overhung exciter rated at 54 V 660 A. It is started as an ordinary slip-ring induction motor by means of an external rotor resistance, and when it reaches 98 per cent. of synchronous speed, d.c. excitation is applied to the rotor to pull the motor into synchronism.

Phasing Out

An interesting feature of the design is the method adopted for phasing out prior to putting the machine into service. Seeing that the driving motor and the synchronous condenser will be connected to the same electrical system (albeit at different voltages) the phase relationship between the two units has to be such that when the motor has been synchronised the condenser is in phase. To build a machine in which this phase relationship is inherently correct would involve undue difficulties in the shops, and some method of adjusting the phase angle between motor and condenser must be provided. An obvious method is to fit the condenser with a rocking stator, but it would be expensive and in the case of the Malvern machine was regarded as unsatisfactory.

To meet this difficulty a method has been devised of electrically rotating the rotor by changing the position of the poles on the driving-motor rotor—an adjustment obtained by altering the distribution of field current in the rotor winding. This is a normal three-phase star-connected winding, and for synchronous operation two of the phases are connected in parallel and the d.c. supply connected to the common terminal and the terminal of the other phase. In order to change the current distribution in the windings a phasing resistance is connected between the parallel windings, and the distribution of field current in the windings is altered by moving the tapping point along the resistance. The value of phasing resistance is so chosen that a variation in the phase angle of $\pm 18°$ can be obtained. Any larger changes of angle that may be necessary can be obtained by reversing the condenser excitation, changing over the phasing resistance to another pair of phases, or changing the position of the coupling between the motor and the condenser. By a combination of these four methods any movement of phase angle between 0° and 360° can be obtained. The phasing is set before the machine leaves the works but can be reset at any time on site.

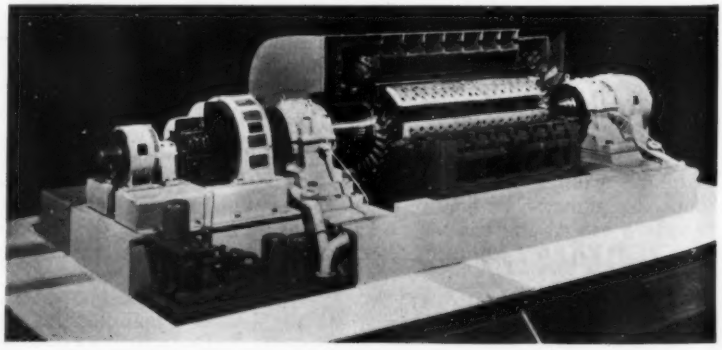


Fig. 3. Model partly dismantled to show construction of condenser and withdrawal of oil pump and strainers

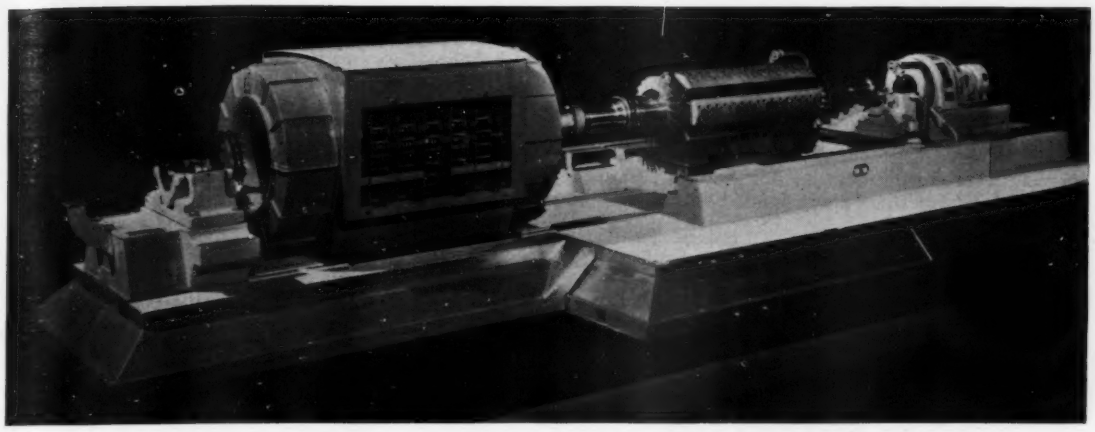


Fig. 4. Model arranged to show method of dismantling. The exciters have been removed, the exciter-end bearing and its supporting beam slid back, the stator moved over on rollers, the driving motor uncoupled, and the rotor mounted on a movable cradle

Lubrication and Cooling

The lubrication system is designed so that all normal servicing and maintenance can be carried out while the machine is running. The oil tank is partly below floor level at the driving-motor end of the set, and contains two motor-driven low-pressure pump units, one acting as standby. The standby unit can be readily disconnected and lifted out complete while the other is in service (see Fig. 3). Each pump is fitted with duplicate strainers, either of which can be lifted out for cleaning at any time. Should the oil pressure fail, the standby pump is started automatically.

These pumps deliver to a bank of four oil coolers in parallel (Fig. 2). Three coolers suffice for normal operation, and the standby cooler can be disconnected and withdrawn without interfering with operation. From these coolers the oil is delivered to the sumps of the two main bearings, which are of the ring-oiled type, the used oil returning by gravity to the tank.

For use when the machine is being started, a high-pressure pump unit is also mounted in the oil tank, giving a direct pressure feed to the bearing liners.

As already mentioned, the air coolers are mounted at the sides of the machine (see Fig. 2), and are covered by removable cowls to give a totally enclosed ventilation system. Air circulation is assisted by cast-aluminium axial-flow fans mounted on the ends of the rotor body.

Assembly and Dismantling

We will now describe the method of dismantling the machine without the use of a heavy crane, the entire operation being carried out with the aid of a 3-ton crane and four 20-ton hydraulic jacks. Assembly, of course, proceeds in the reverse order. At the driving-motor end the main bearing stands on the closed end of the concrete plinth, but that at the exciter end is carried by a deep steel beam spanning the open end of the plinth. The first step in dismantling is to remove the main and auxiliary exciters, an extension shaft being bolted to the main shaft in their place. All enclosing covers and the fan shrouding rings are next removed, and the outer end of the extension shaft is lifted on two 20-ton jacks, operated by a portable oil pump, sufficiently to permit removal of the main bearing bush. The beam, with the pedestal which it supports, can then be withdrawn on skid plates far enough to allow the shaft to rest on packing blocks under the main journal. The jacks and the beam can then be taken away.

The air coolers are now removed, and four jacks are inserted under one side of the stator frame. After lifting slightly, roller trolleys are placed on a rail under that side of the stator. The operation is repeated at the opposite side. Two jacks are now transferred to the outer end of the extension shaft, the packing blocks are removed, and the stator is withdrawn far enough to expose most of the rotor body, further roller trolleys being inserted as required.

The driving motor is now uncoupled from the main shaft, and the complete motor assembly on its base-plate is pulled back sufficiently to allow a lifting bracket to be bolted to the main shaft. Lifting this end slightly on two jacks allows the bearing bush to be removed, and a wheeled truck and cradle to be assembled under the centre of the rotor. All jacks are then lowered and removed, allowing first the stator and then the rotor to be withdrawn.

During our visit to the makers' works the dismantling and assembly operations, as well as the various features of the machine, were demonstrated by an admirable scale model built by members of the Metropolitan-Vickers Long Service Association, and Figs. 2, 3 and 4 are views of this model.

Constructional Features

The stator core is built of silicon-alloy segmental stampings of the straight-back form, with non-magnetic tooth supports and vent spacers. The winding is of particular interest because of the unusually high voltage. It is of the two-layer type, all coils being identical, having formed involute ends, clamped by brass bolts and plates to angle brackets of compressed hardwood. The individual strips of the laminated conductor, and the complete coil, are insulated throughout with mica-silk tape, vacuum-dried and impregnated in bitumen. The coils are jointed at both ends to facilitate insertion or removal without dis-

tortion. Each strip is jointed by electric butt welding.

The rotor body is a steel casting with bolted-on flanged shaft ends, and pole shoes secured by a large number of high-tensile bolts. The field coils are of the rectangular fabricated type, built up from side and end bars, with a dovetailed brazed joint at each corner. Every fifth bar is wider than the others, forming a projecting cooling fin. Adjacent bars are separated by asbestos paper, bonded with a thermal-hardening varnish and solidified under heavy pressure. The coil is insulated from the pole by hard, flat sheets of bakelite-glass board, with thick collars of bakelite-fabric board at top and bottom. Y-clamps support the coil against lateral deformation. Centrifugal forces in a rotor of this size at 15 per cent. overspeed reach 1,000 *g*, and the clamps are secured by dumb-bell extensions which slide into slots of circular section drilled axially in the rotor body.

Abstracts from the World Technical Press

A Novel Emergency Gate

A description is given of a novel type of emergency gate which, it is claimed, can advantageously replace cofferdam gates, stoplogs, and other devices used for closing intakes and other hydraulic structures, and requires but short time and practically no special equipment for erection on site. It is essentially a floating unit constructed of steel sections and plates, and built on the lines of a flat rectangular pontoon, so that it can be easily towed to its place of erection. The gate shown in Fig. 1 below was made to the order of the R.W.E. concern at Coblentz; its overall dimensions are 15·75 m. by 8·6 m., and its weight is 35 metric tons. The four corners of the gate constitute buoyancy tanks which, together with trimming tanks, form the long sides of the rectangle or, in other words, the top sill of the closed gate; partitions parallel to the short sides divide the space between the two rows of tanks into eight open compartments fitted at their lower sides with flooding cocks. The trimming tanks can be filled with compressed air by means of a piping system and of a manifold which can easily be connected by hose pipes with an air compressor. The floating tanks are calculated so as to have a buoyancy smaller than the moment of immersion resulting from the weight of the gate; on the other hand, the buoyancy of the floating tanks, added to that of the trimming tanks, is such as to ensure an adequate amount of freeboard, even with fully flooded open compartments.

The gate is placed into position as follows: once it has been towed to the opening to be closed and lies floating between the gate piers, it is lifted by means of a simple winch so that the bolts acting as a kind of hinge-pins on either side at the top can easily be inserted into holes provided in the gate piers; the air piping system and its manifold are then connected with the hose pipes leading to the compressor, and the flood cocks are opened. As the open compartments connect with the trimming tanks, these can also be flooded one after the other. After the air has escaped, the gate, describing a 90° arc, revolves slowly into its closing position. If necessary the revolving motion of the gate can be regulated by reducing or increasing the admission of compressed air into the trimming tanks.

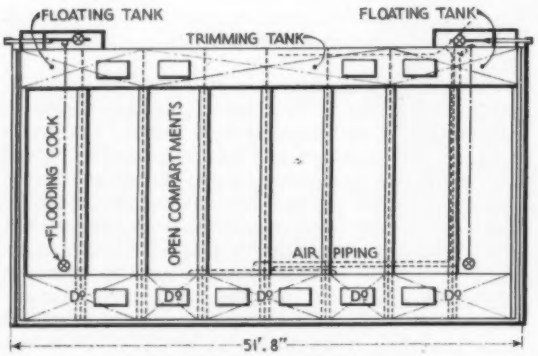


Fig. 1. Layout of emergency gate

To open and remove the gate, the whole procedure is reversed. First of all the flooding cocks of the open compartment are opened, so as to obtain an equal pressure of the water on both sides of the gate; compressed air is then blown into the trimming tanks, thus expelling the water which filled them; the gate regains its buoyancy and returns to its floating position.

At the Coblentz power station it took, at a first attempt, no more than 35 minutes to bring the gate into the closing position after the bolts had been inserted into the holes of the gate pier. Return to the floating or open position required but seven minutes.

This interesting type of emergency gate is manufactured by the M.A.N. concern at their Gustavsburg works, and by the G.H.H. concern at their Sterkrade works. (Knoetzelein, Coblentz, *Die Wasserwirtschaft*, Vol. 42, No. 5, Feb. 1952, p. 177, 3 pp., 9 ff.)

Improving Run-of-River Plants

Where large volumes of water are available at relative low heads power utilisation can only be achieved by setting up power houses with a relatively large number of small turbines; this practice, however, runs counter to the modern trend of plants with a restricted number of large-size units. It is claimed that the arrangement shown in the appended diagram solves this problem though increasing the operating head by means of a propeller pump driven by an auxiliary turbine.

Each such complete unit consists of an auxiliary turbine with direct-coupled turbo-pump on a horizontal axle, and of a vertical axle generating set. The water actuating the main turbine is raised by the turbo-pump to an operating head exceeding the level of the water at the intake.

The propeller type pump has been selected on the basis of the experience gained in the construction of large pumping units, and of the results achieved in ship testing channels.

According to a table at the end of this article a natural head of 4·5 m. at the intake could be raised,

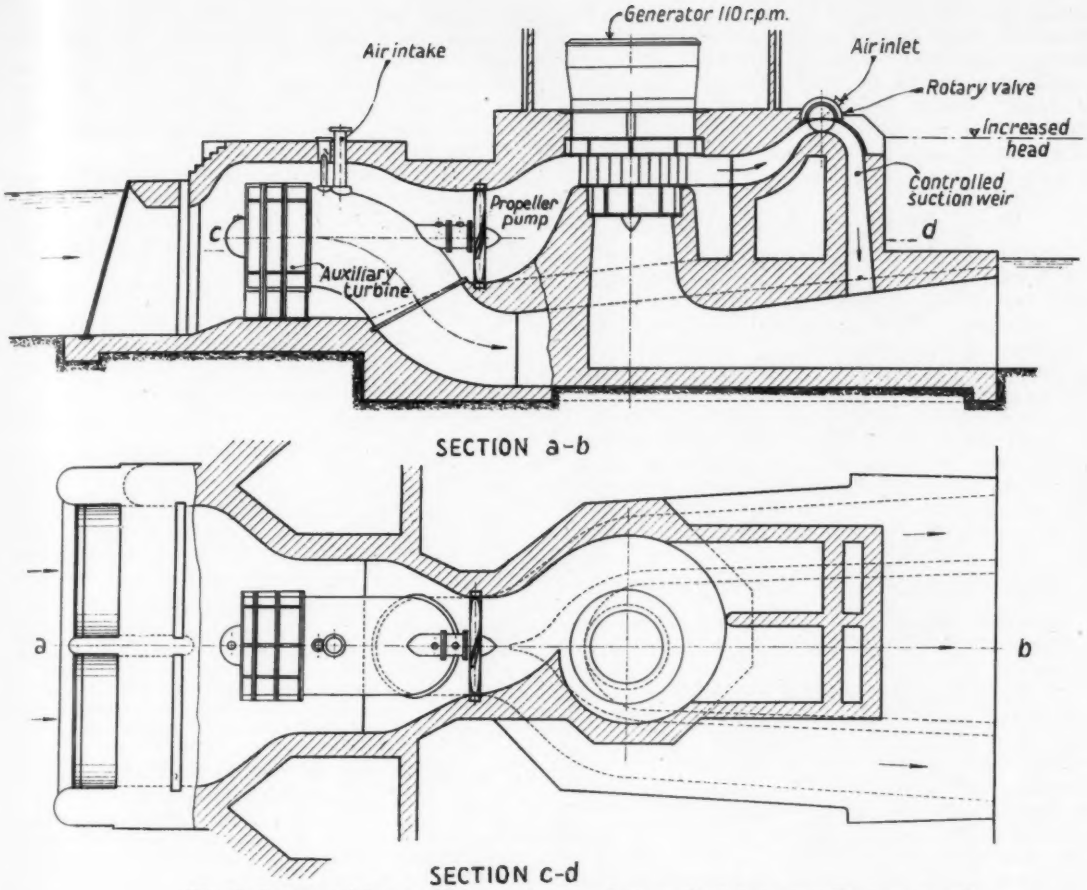


Fig. 1. Suggested layout for run-of-river plant embodying propeller-pump unit

by means of this arrangement, to 8·1 m., corresponding to an approximate output of 4,750 to 5,950 metric h.p. at a speed of about 120/115 r.p.m. It appears, however, that this new system has not yet been tested in actual practice. (Professor Euler, *Die Wasserwirtschaft*, Vol. 42, No. 5, February 1952, p. 174, 4 pp., 2 ff.)

Earthfill Dam in the Tropics

Wet-weather earthfill dam construction practices were tested to an extreme last summer when unusually heavy floods occurred in Mexico's Papaloapan Valley, where Presidente Aleman dam is nearing completion. This dam, 2,700 ft. in length with a maximum height of 200 ft., is being built on the Tonto River, as the first major structure in a comprehensive plan for a tropical watershed which covers 18,000 sq. miles of coastal territory close to the isthmus of Tehuantepec. The Tonto River, one of the main tributaries of the Papaloapan, flows in typical tropical country, where rains occur more frequently than twice daily during a five-month period; impervious material is plentiful but placing it is a problem and depends largely on the condition of the haulage roads. Protecting earthwork already in place is another major problem.

Flood control is the main purpose of this project but other purposes include power generation, navigation improvement, and auxiliary irrigation for 375,000 acres. In addition to Presidente Aleman dam, other principal parts now in course of construction include a 7,500-ft. dike at the far end of which a 160,000 cusec spillway will be built when the major embankments of the project are completed.

For the time being the dam with its outlet works is able to handle the largest floods without overtopping. The 1952 summer floods, the greatest in several decades, brought about a temporary suspension of work but little actual damage was done. (*Engineering News-Record*, p. 34, 2 pp., 4 ff.)

Hungry Horse Scheme

The 3,100,000-cu. yard Hungry Horse dam was put into operation on October 1 when the first of the four 71,250 kW generators was put under load. A second generator went on the line last December, and the third and fourth will follow this year in August and December respectively. The power-short Pacific Northwest thus benefits from the first power to come from a post-war federal construction project. Other power has been added at Grand Coulee dam last year, and McNary dam is due to add more this year; but Hungry Horse is the first federal project started in post-war days to deliver power. A diagram in the original text shows the extent to which down-

stream plants now built or under construction on the Columbia River will benefit from Hungry Horse storage. Additional benefits will ultimately go to proposed dams and plants, viz.: John Day, Ringold or Richland, Priest Rapids, Rocky Reach, Wells, Boundary, Noxon Rapids, Trout Creek, and Paradise. (*Engineering News-Record*, October 2, 1952, p. 24, 1 p., 1 f.)

Power Projects in Bombay State

The general plan of power development worked out for Bombay State is reviewed and commented upon, with special reference to the Koyna hydro-electric project which is to fill the gap now existing between the Jog Falls and the Tata area. Koyna River, a tributary of the Krishna, affords excellent facilities for the creation of a large reservoir and the setting-up of a high-head power plant with an ultimate capacity of about 500,000 kW within easy reach of the Bombay-Poona area and the neighbouring industrial centres. (Dr. B. K. Ram Prasad, *Indian Journal of Power and River Valley Development*, Vol. 2, No. 8, July 1952, p. 11, 6 pp., 2 ff.)

Flow Analysis in Hydraulic Structures

An exhaustive account is given of a systematisation of the analysis of three dimensional flow in hydraulic structures, as developed in model tests in connection with the Hirakud dam project. This study is divided into three parts. Part I deals with the theoretical aspects of the question: kinematics of rotational motion, field equations for irrotational motion, boundary conditions, etc. These theories are applied in Part II to flow through a sluiceway barrel, and in Part III to flow through the inlet transition of a deep set sluiceway. (M. K. Ganguli and S. K. Roy, *Irrigation and Power*, Vol. 9, No. 1, January 1952; Part I, p. 46, 7 pp., 6 ff.; Part II, p. 57, 10 pp., 8 ff.; Part III, p. 76, 11 pp., 11 ff.)

Missouri Flood Control

An account is given of the work now in progress with a view to reducing future Missouri flood threats, and avoiding a recurrence of the extensive damages caused by the floods of last spring. Exceptionally good weather has enabled the Corps of Engineers to make better progress than was expected. The west abutment of Garrison dam has been completed to crest elevation and faced with rock, the east abutment has reached a height of 85 ft., the spillway channel is being excavated, and placing of the concrete in the downstream spillway slab was started at the end of October; closure is planned for next May or June.

The closure of Fort Randall dam last July affords a new measure of protection from any future flood originating on the upper river in the Dakotas and Montana.

Construction at Oahe dam near Pierre, S.D., was concentrated last season on placing a rockfill embankment to form the west abutment while at Gavins Point dam, near Yankton, S.D., one or two river channels were blocked off with a long dike to expedite the placement of Stage I embankment.

Water from Fort Peck reservoir, in Montana, is being released throughout this winter to ensure an empty flood spool next spring; Fort Peck dam is the workhorse on the Missouri and it has not been forgotten that, by impounding the maximum amount of water possible, it knocked 1·5 to 2 ft. off the flood crest last April and, with the help of Heart Butte and Shadehill dams, prevented damage estimated at $14 million.

Two other dams completed in 1952, Harlan Country dam on the Republican River in Southern Nebraska, and Boysen dam on the Big Horn River in Wyoming, will also contribute to flood protection in the Missouri River valley.

In spite of all this progress, General W. E. Potter, Missouri River Division Engineer, warns that satisfactory and dependable flood control on the Missouri River is still several years away. (*Engineering News-Record*, November 6, 1952, p. 27, 2 pp., 1 f.)

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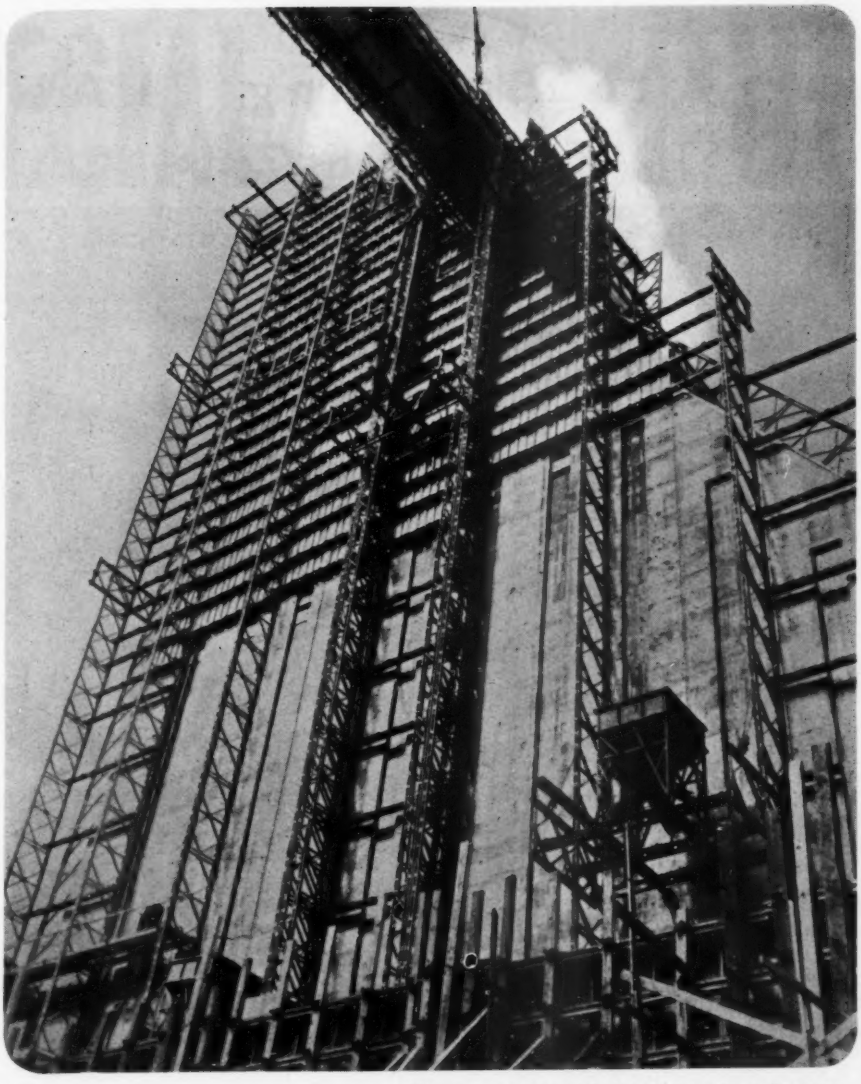

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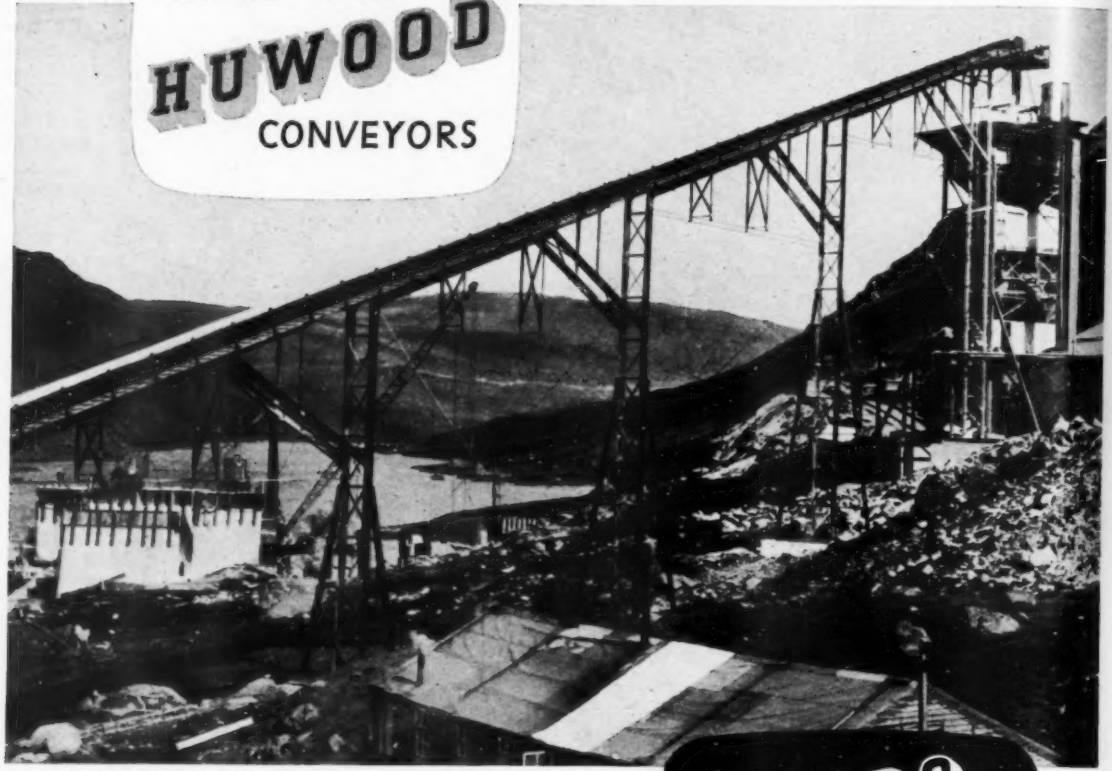

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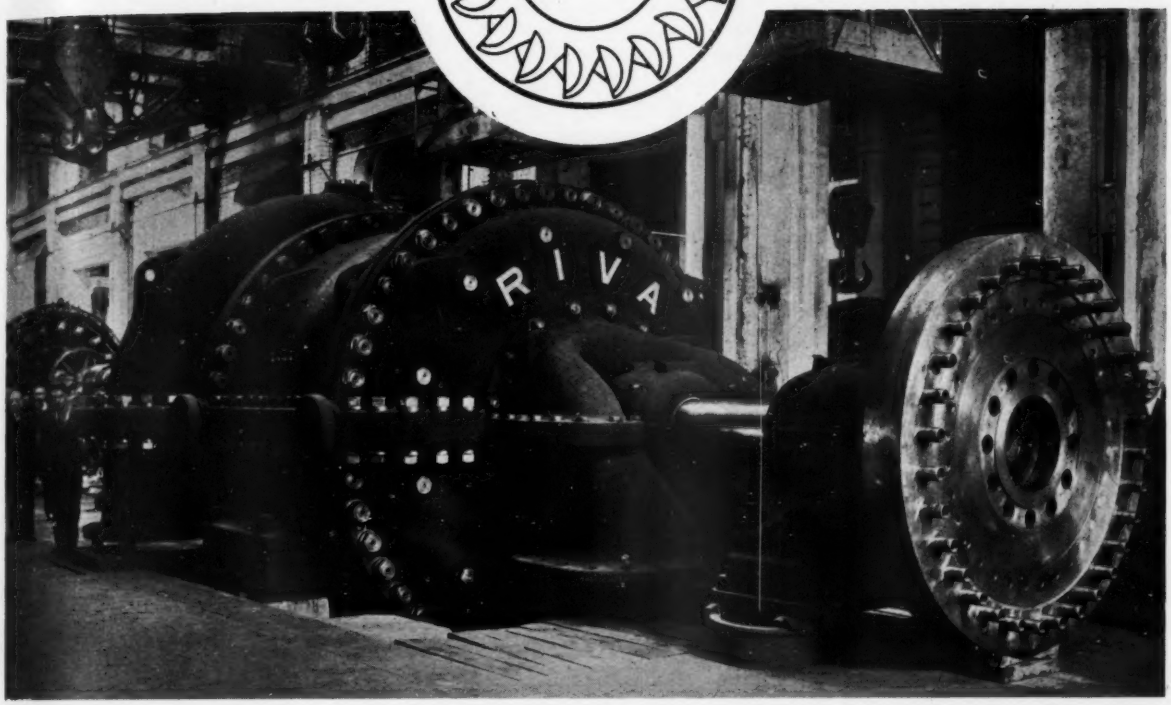

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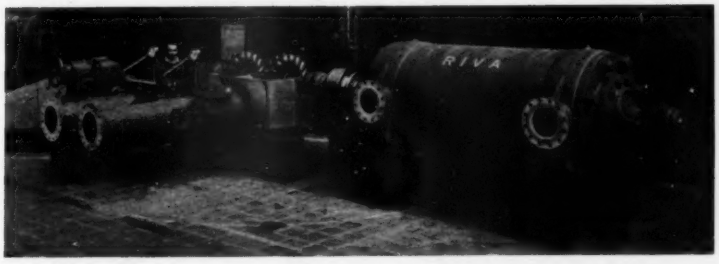

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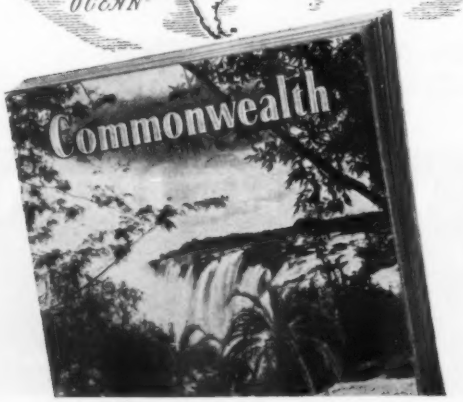

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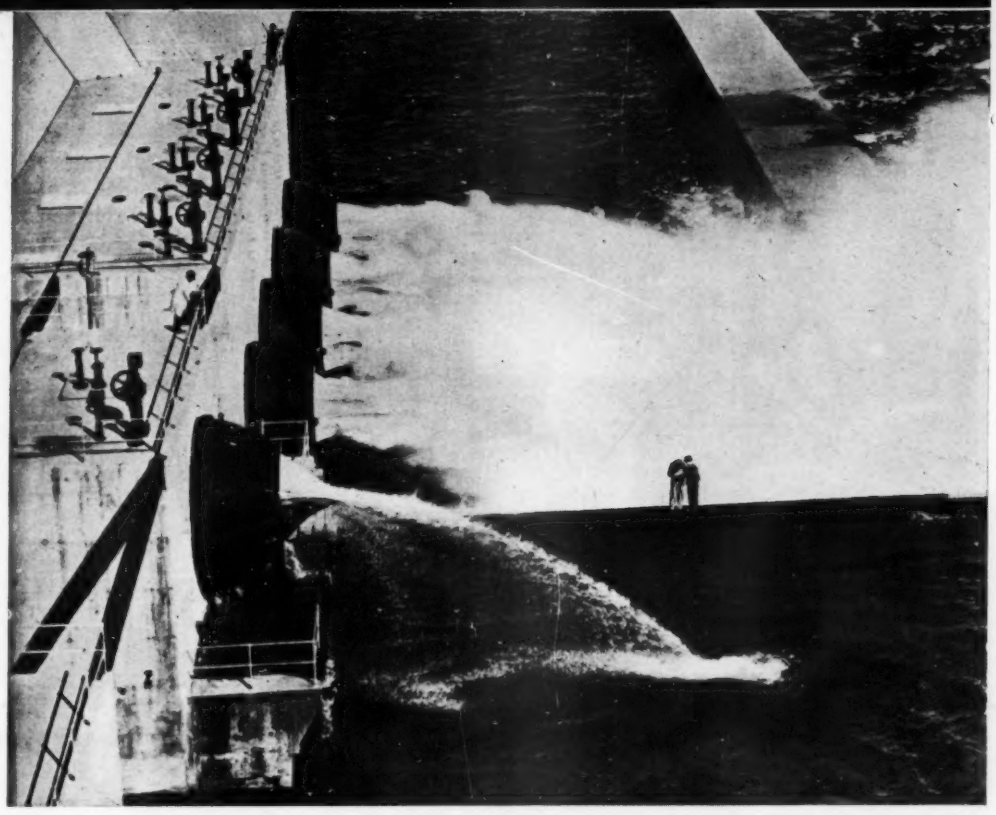

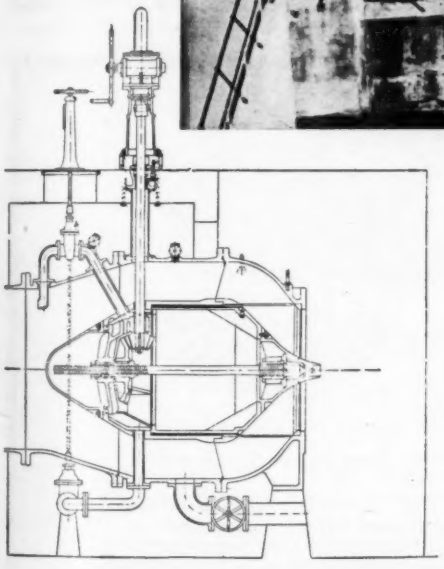

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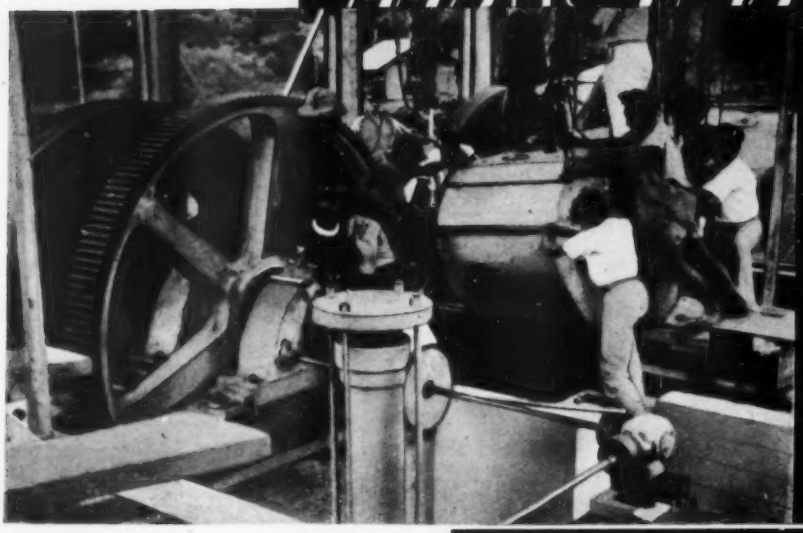

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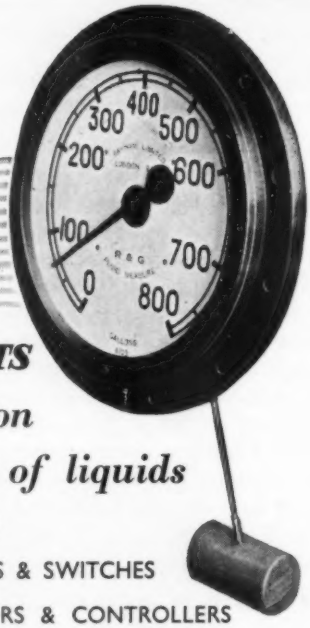

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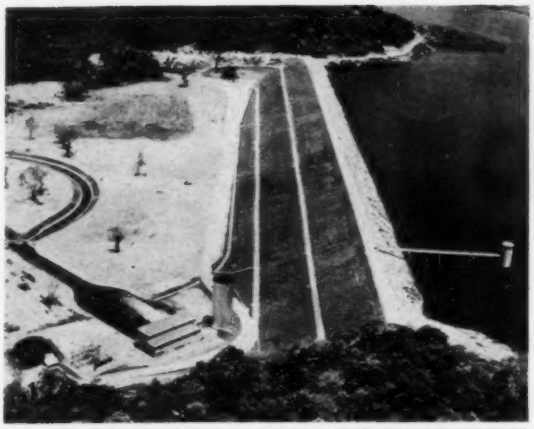

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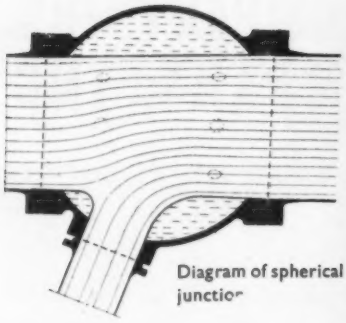
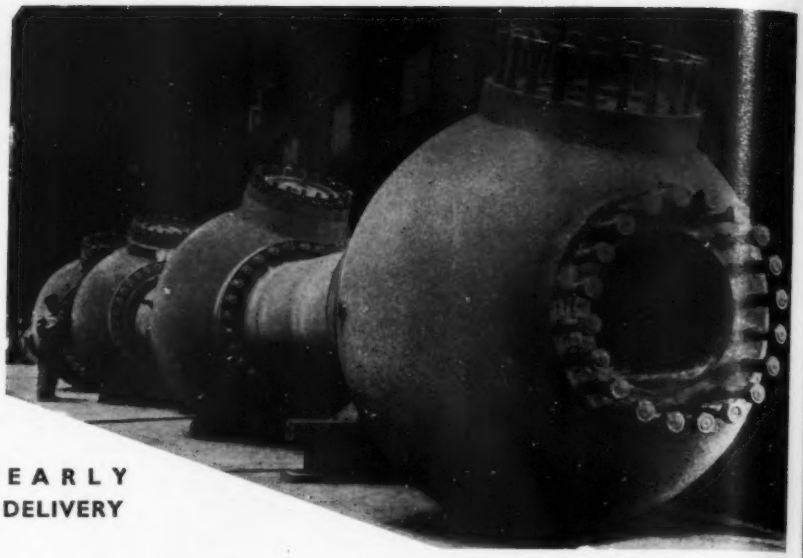


Diagram of spherical junction



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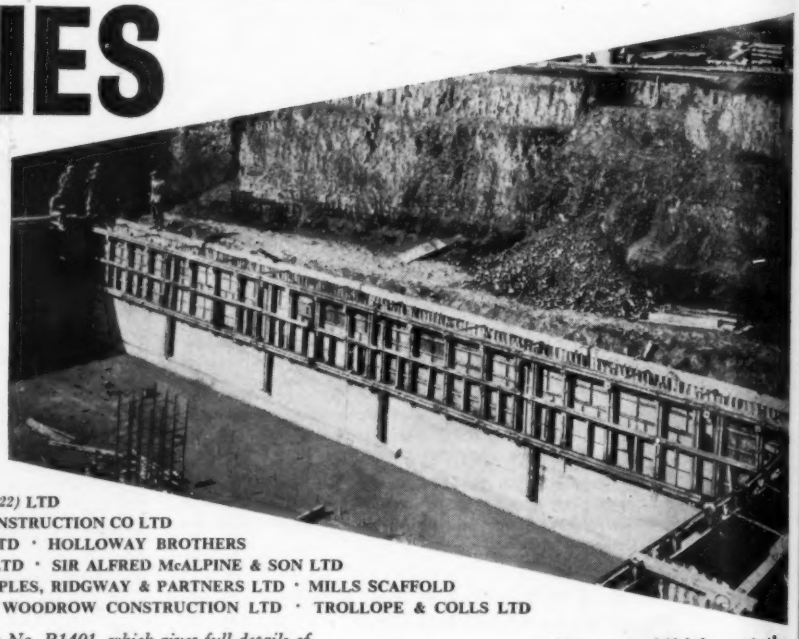

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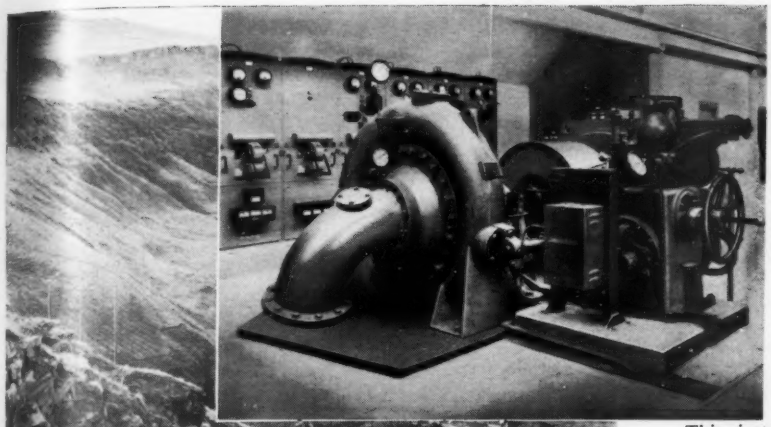

STORR LOCHS HYDRO-ELECTRIC SCHEME ISLE OF SKYE

Interior of the power station showing one of the two 1,150 B.H.P. GILKES Francis Turbines

This installation is one of the North of Scotland Hydro-Electric Board's smaller stations, supplying the Isle of Skye and the adjacent mainland. A dam has been constructed impounding Loch Leathan and Loch Fada, making them into a single storage reservoir. From this, a 42-inch diameter pipeline 2,700 feet long leads to the power station almost at sea level.

The station contains two 1,150 B.H.P. 1,000 r.p.m. **GILKES** Francis Turbines operating on a nett head of 435 feet and driving 800 kW alternators. Provision is made for the installation of a third unit.

Looking down the pipeline to the power station on the shores of Bearreraig Bay

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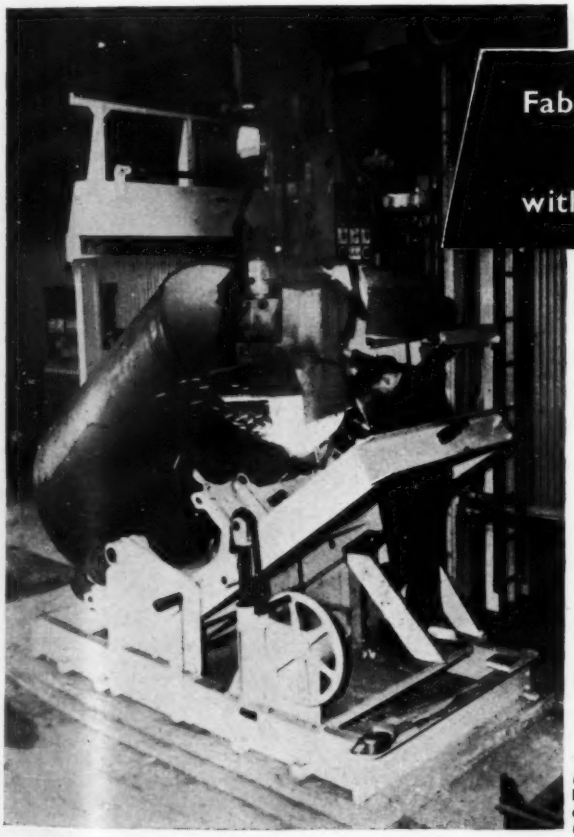

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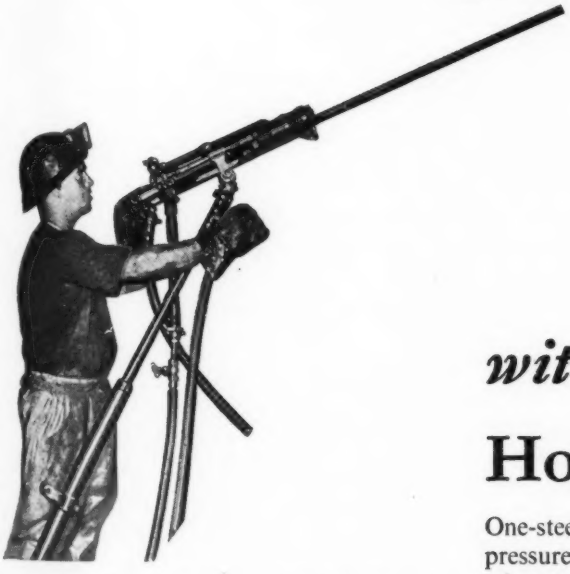

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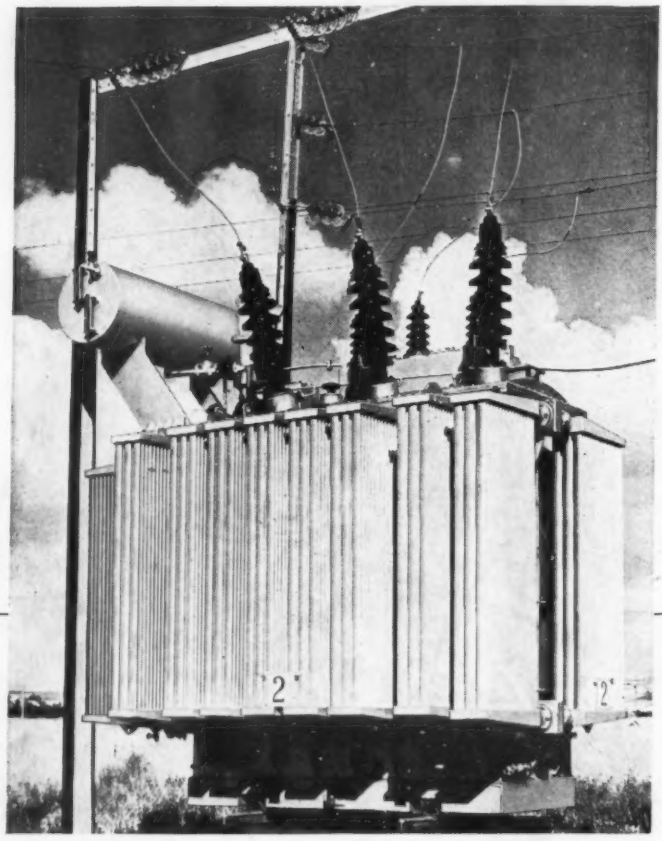

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